

The Scientific Evolution of SETI@home

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<http://setiathome.berkeley.edu/>

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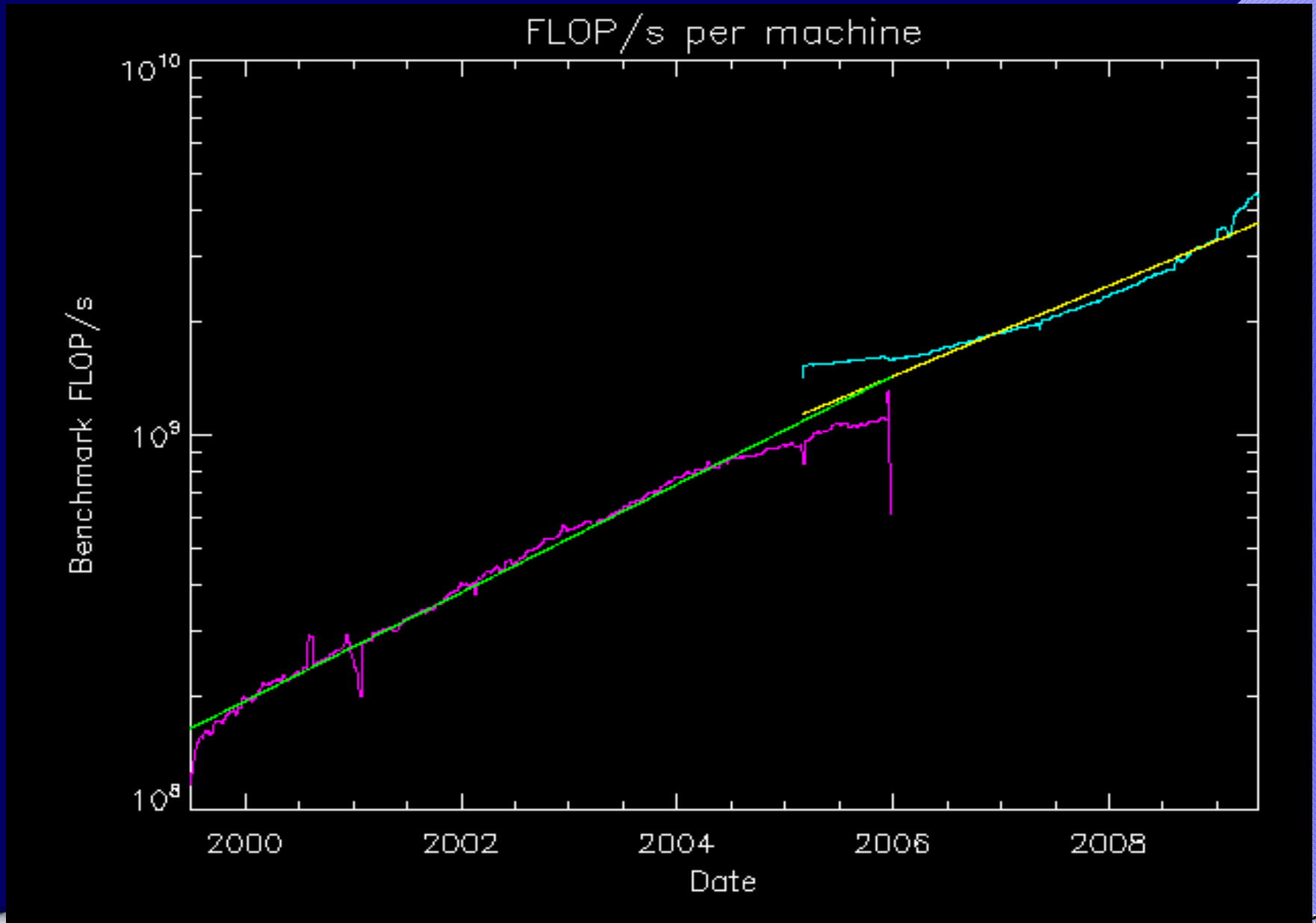


SETI@home Evolution

1. Evolution of technology
2. Evolution of our volunteer base
... drive ...
3. Evolution of the SETI@home client
4. Evolution of the SETI@home server
5. Evolution of backend processing
6. Evolution of additional applications



Technology Evolution

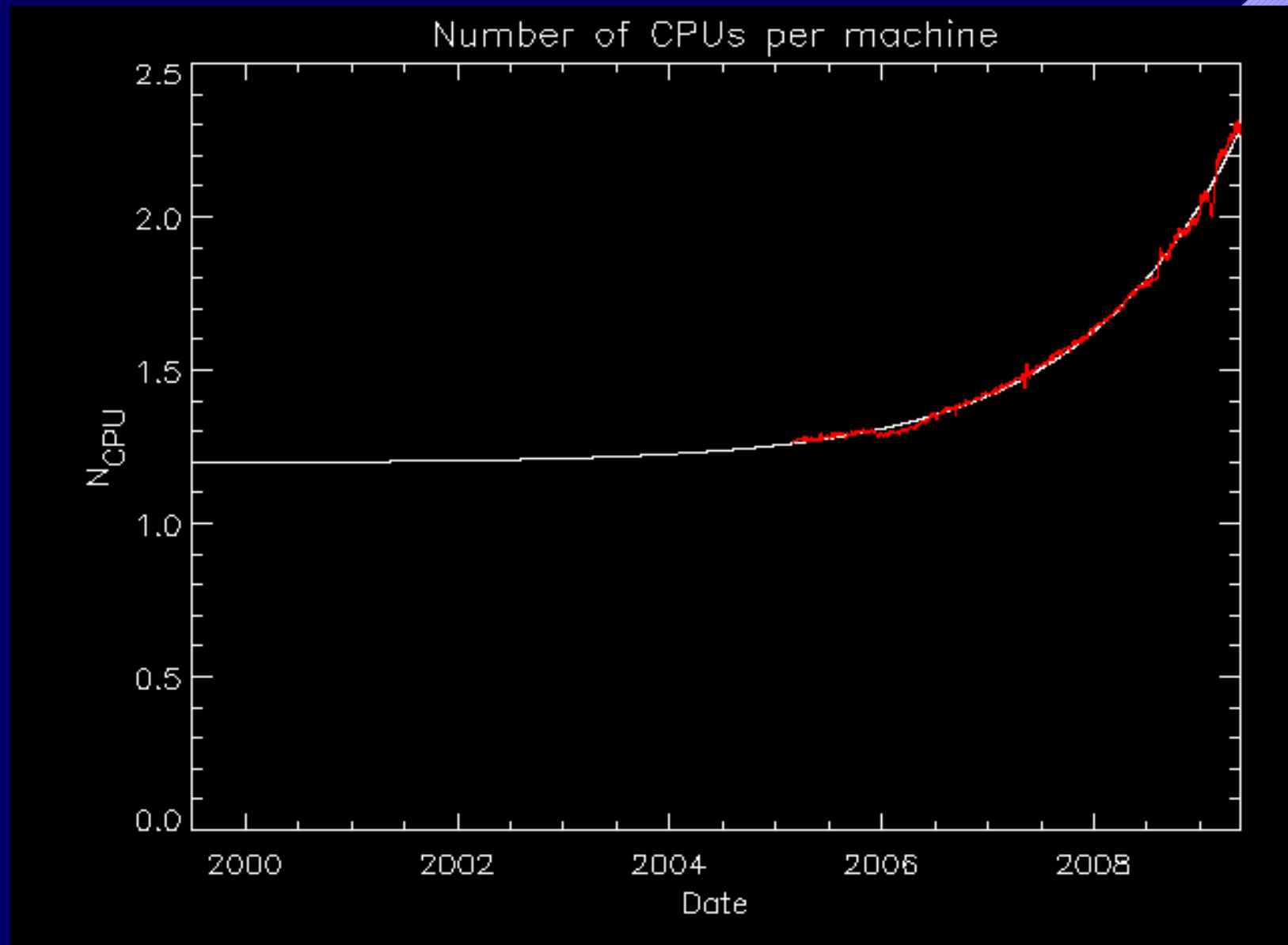


SETI@home

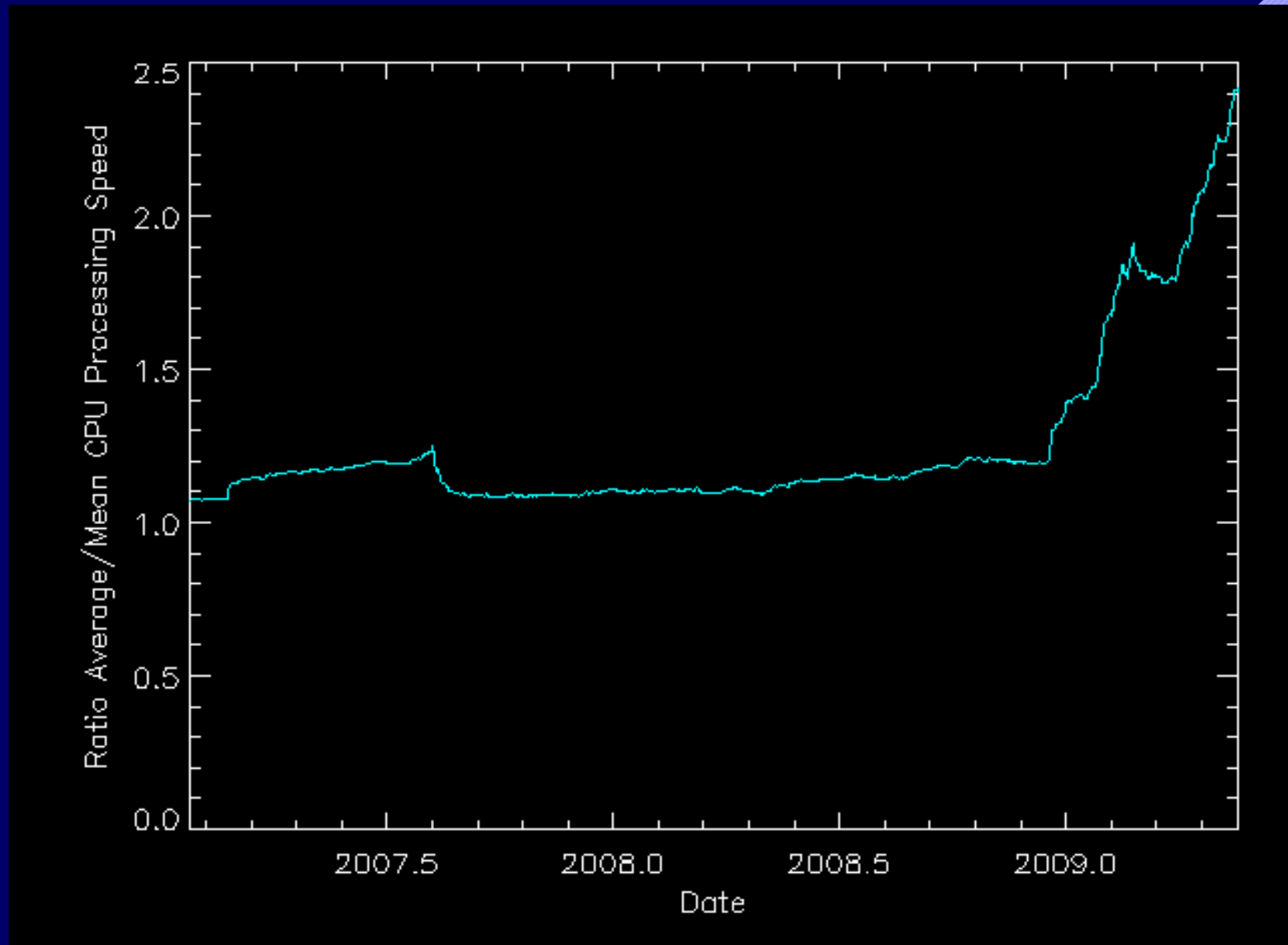
The Search for Extraterrestrial Intelligence



Technology Evolution



GPU Based Computing



Evolving technology at the telescope

Photos Courtesy NAIC Arecibo Observatory, a facility of the NSF



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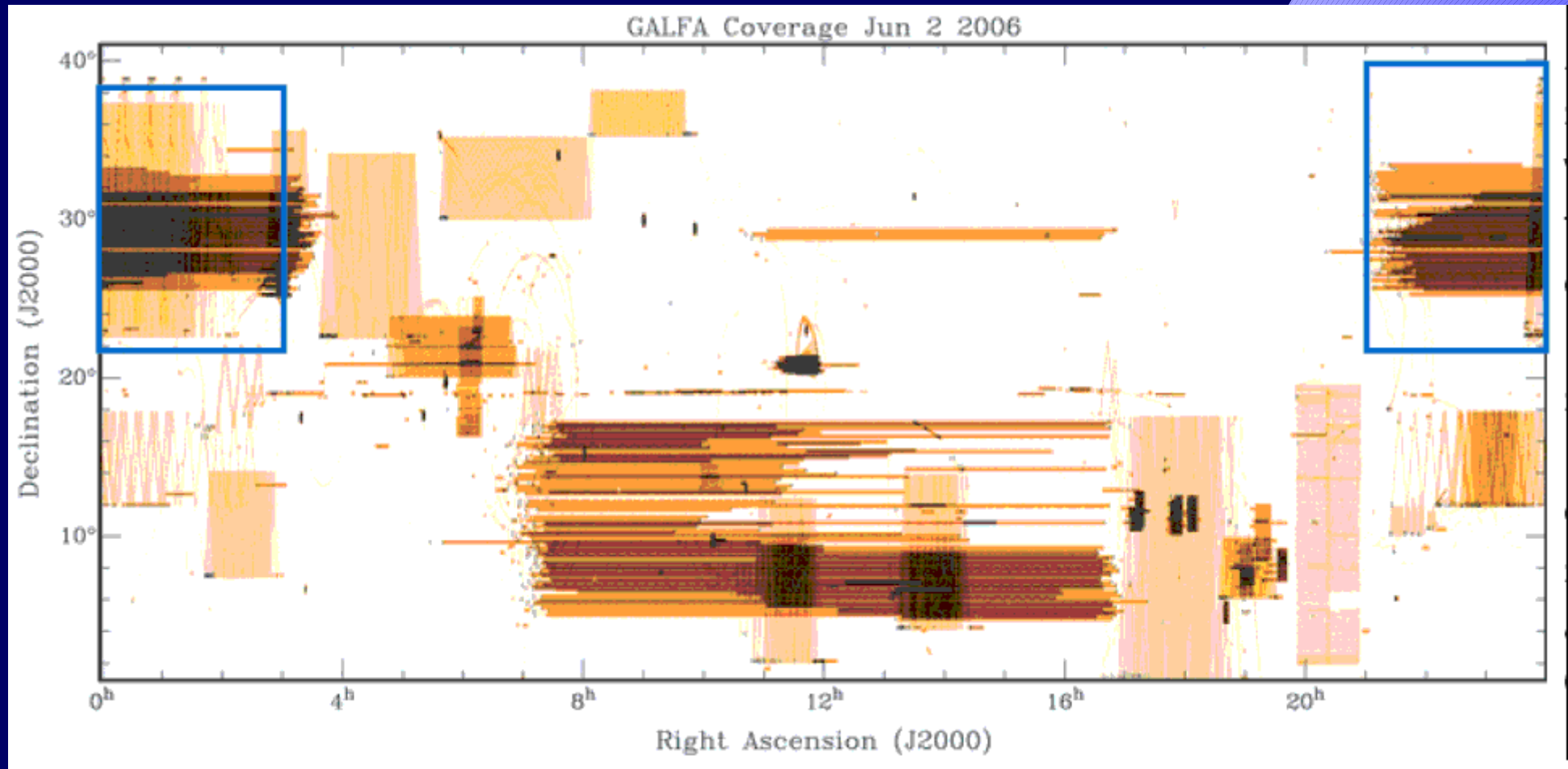
The Search for Extraterrestrial Intelligence



Arecibo L-band Feed Array (ALFA)



Commensal Observations with G-ALFA and P-ALFA



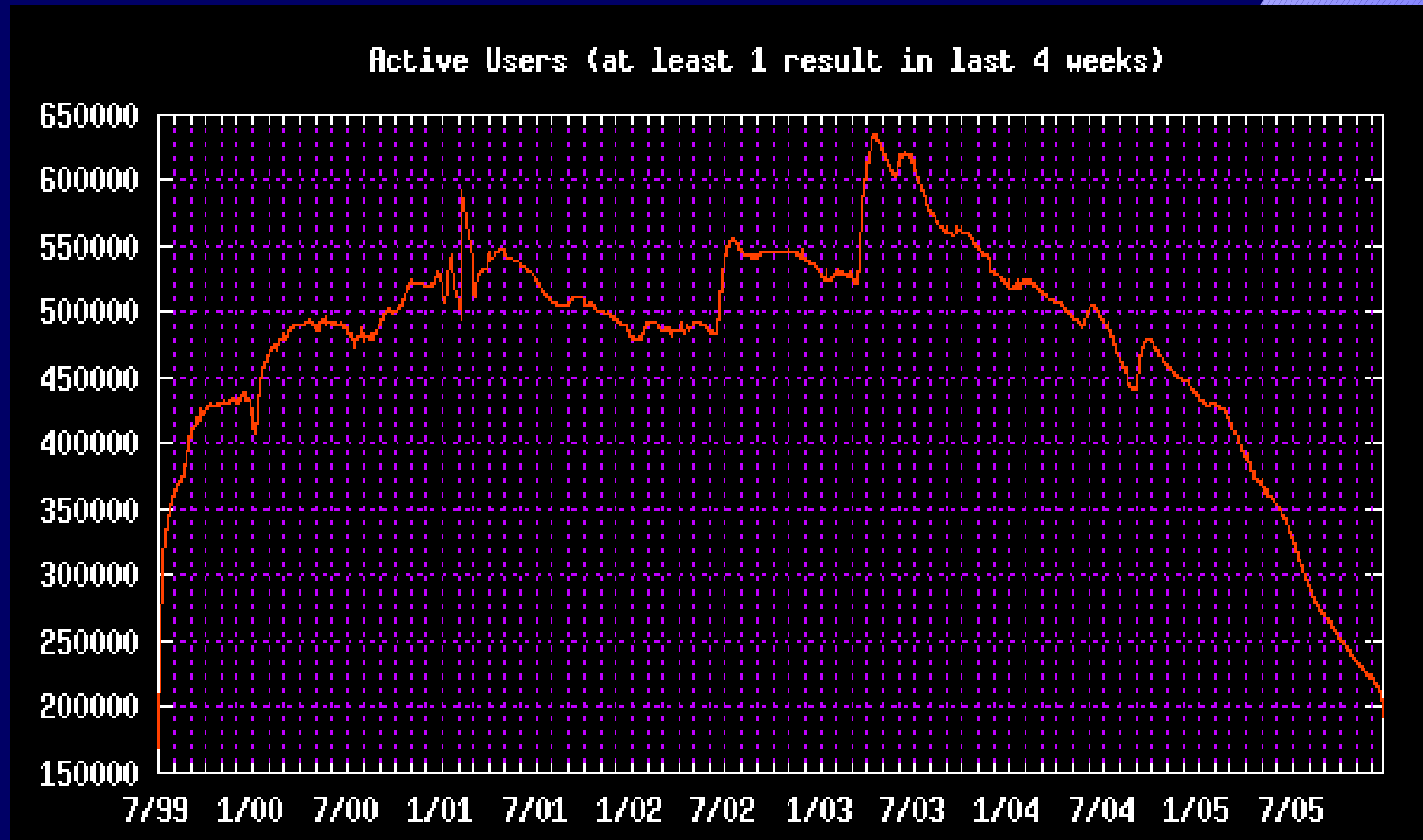
Volunteer Base

Optimization of the SETI@home application enabled by open source transition.

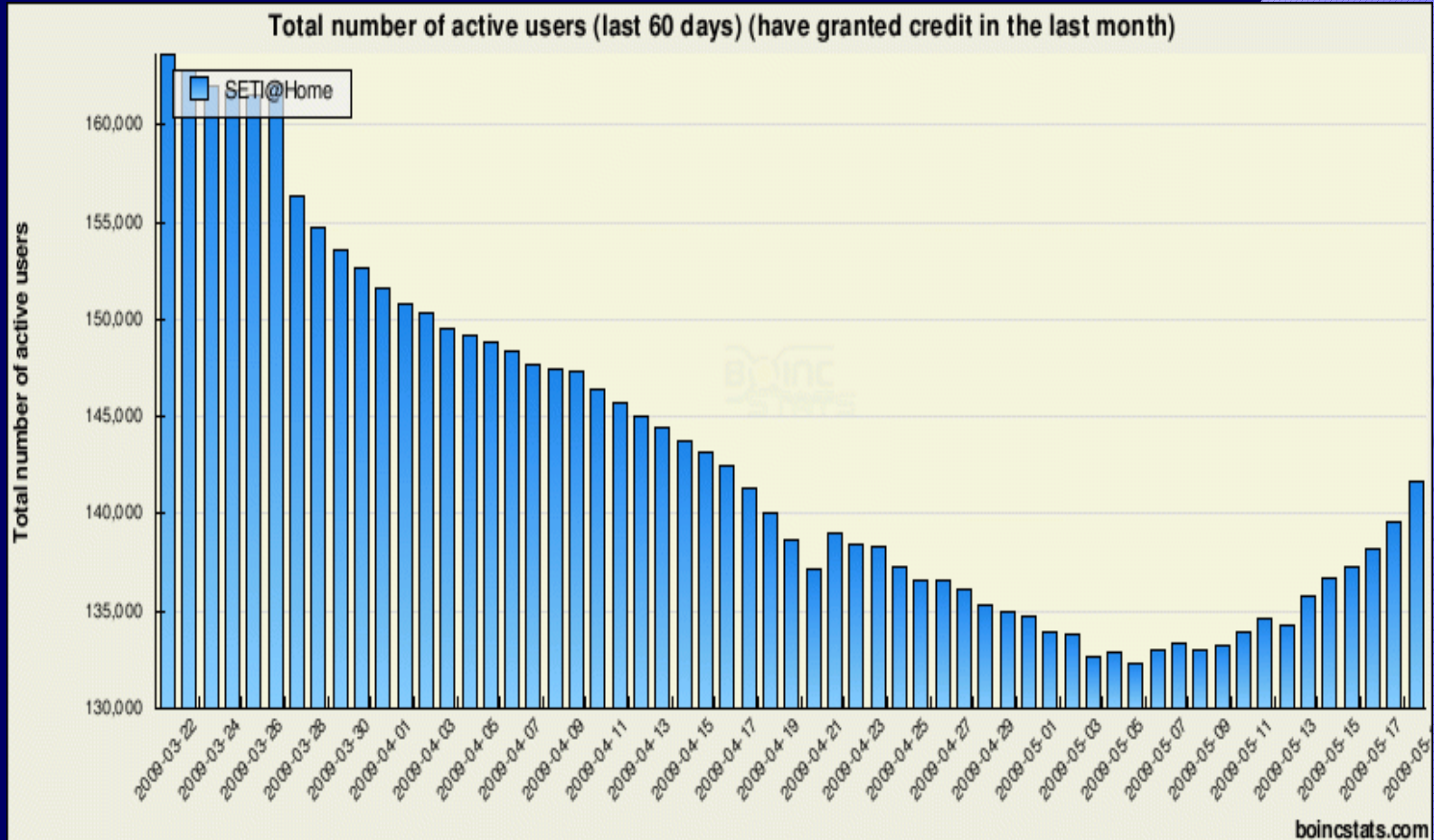
- Current “stock” application 8-12x faster than the original SETI@home code
- Processor specialized versions available online that are 2-3x faster than the “stock” app.



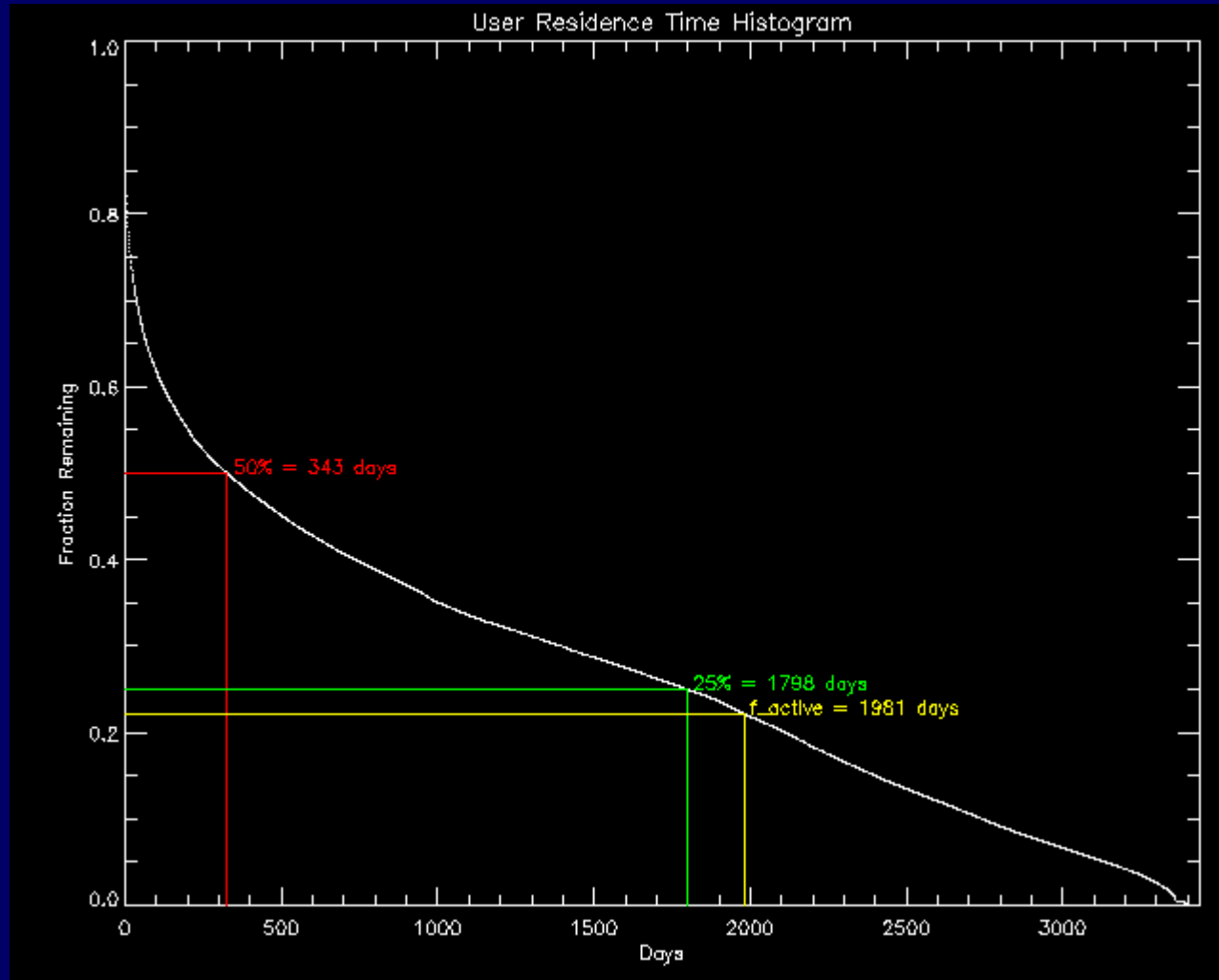
Volunteer Base



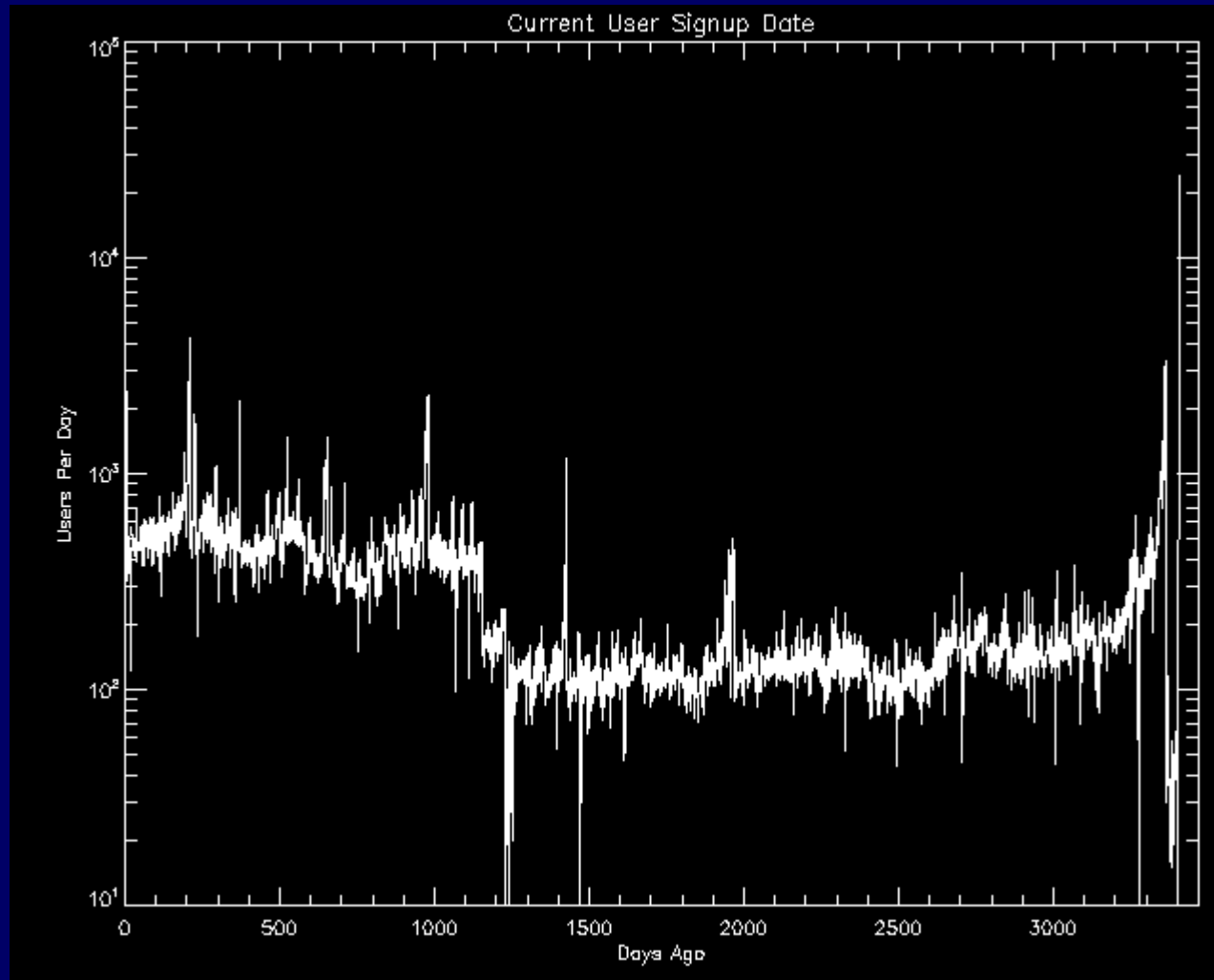
Volunteer Base



Volunteer Base



Volunteer Base



Overall

The computing power available to SETI@home has continued to increase.

This allows us to increase the complexity of the algorithms contained in SETI@home.



The SETI@home Client

Baseline subtract to remove broadband variations (21cm hydrogen line)

for Doppler drift rates from -100 Hz/s to +100 Hz/s {

for bandwidths from 0.075 to 1220 Hz in 2X steps {

Generate time ordered power spectra.

Search for short duration signals above a constant threshold (spikes)

for each frequency in the power spectra {

Search for faint signals matching beam parameters (Gaussians)

Search for groups of three evenly spaced signals (triplets)

Search for faint repeating pulses (pulses)

}

}

}



Changes to the SETI@home Application

1. Bug fixes

Chirp rates off by 2X.

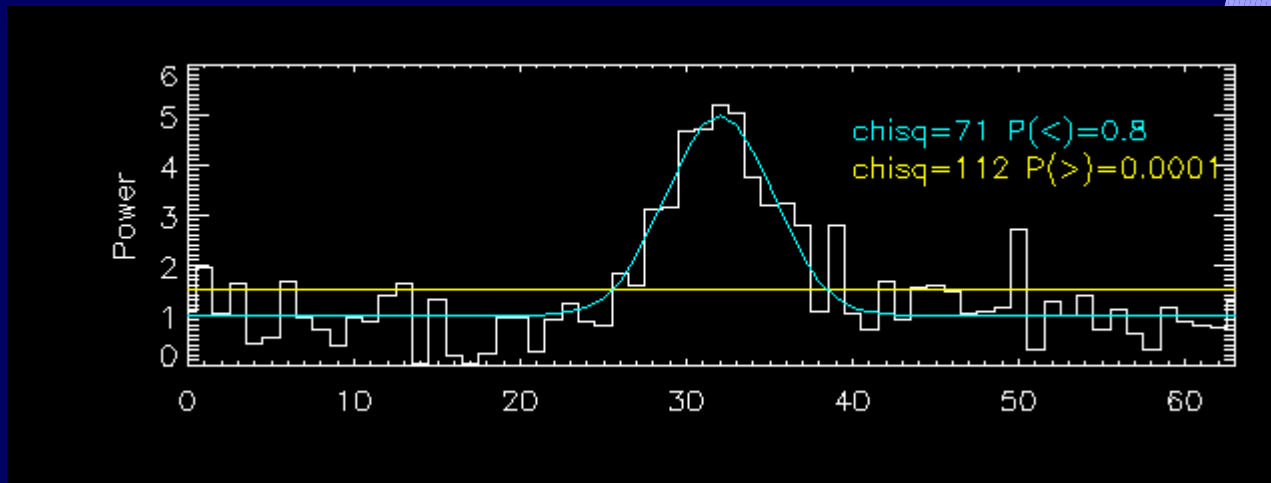
Typo in incomplete gamma function.



Changes to the SETI@home Application

2. Gaussian fitting.

Originally tried to combine goodness of fit and power into one parameter. (Dominated by powerful, poor fitting Gaussians).

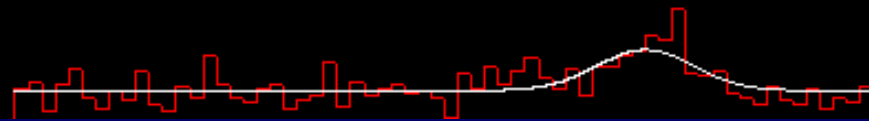


Now use χ^2 of Gaussian fit ($P_g > 0.05$) and χ^2 of null hypothesis ($P_n < 2.5 \times 10^{-8}$).

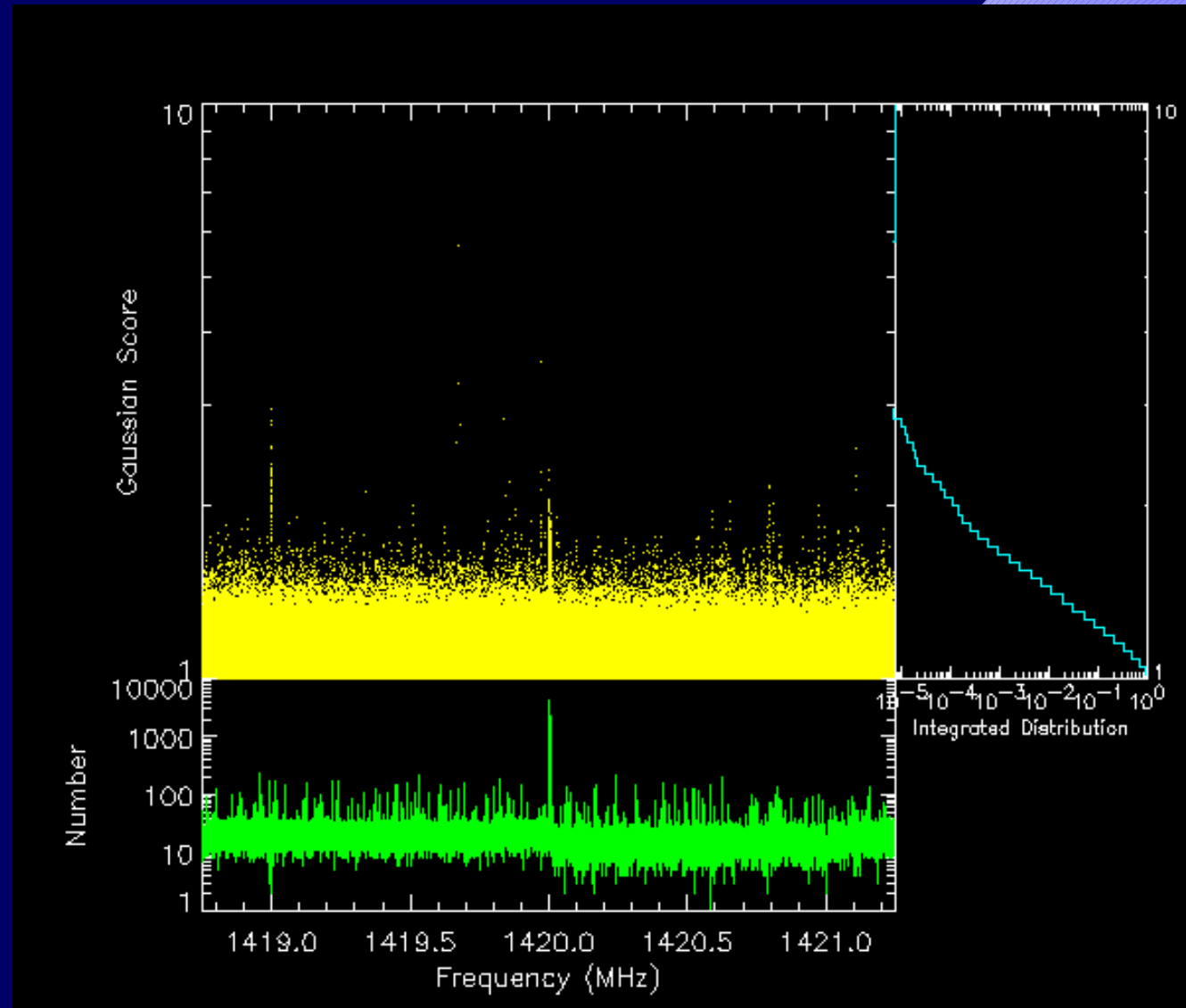


Gaussians

Best Gaussian: power 1.20, fit 3.960



- χ^2 fit to beam profile (vs time).
- Gaussian fit must be below a χ^2 threshold and null hypothesis test must be above a χ^2 threshold
- Score proportional to log probability of arising due to noise
- Sensitivity
 $\sim 2.1 \times 10^{-25}$ W/m²

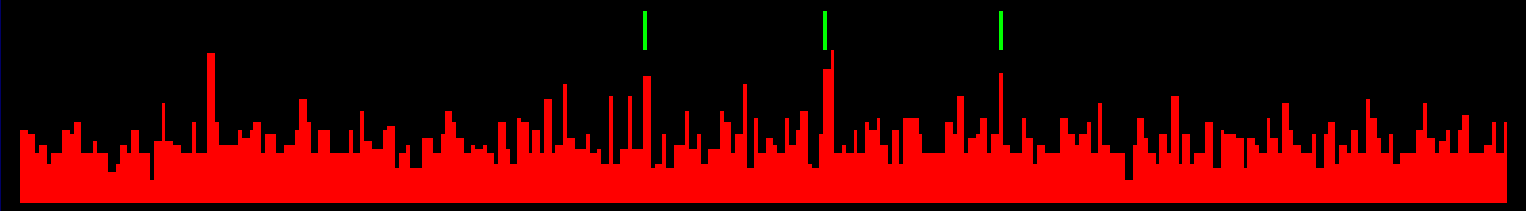


Changes to the SETI@home Application

3. Pulse Finding:

Triplets. Three evenly spaced spikes above variable threshold within 1 beam crossing time.

Best Triplet: power 8.22, period 1.7097



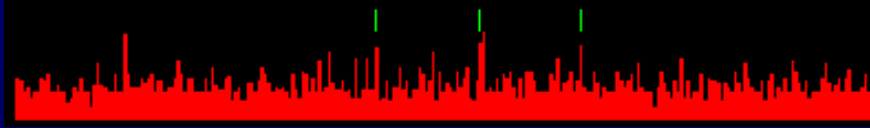
Minimal CPU time required.

Linear period spacing.

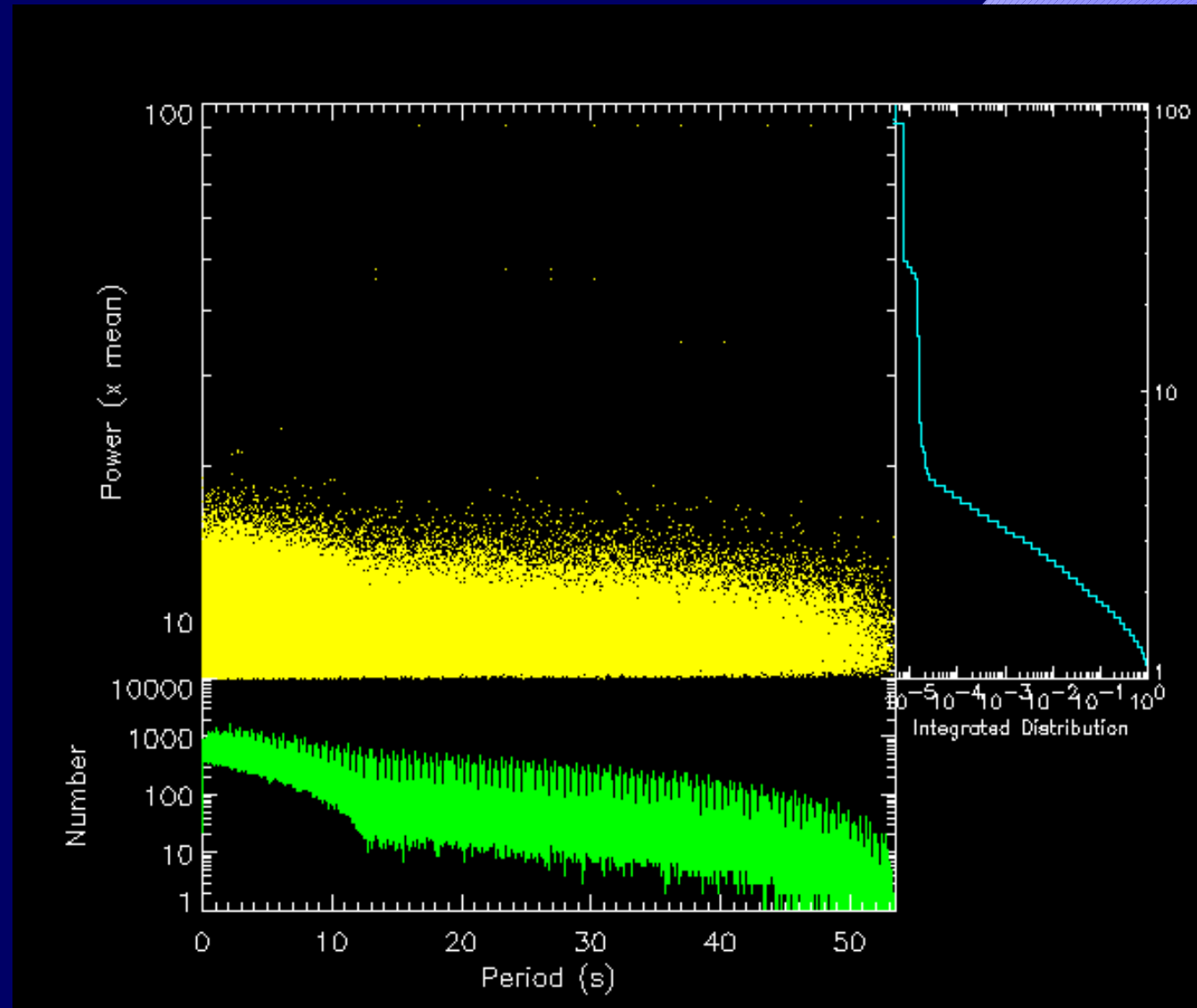


Triplets

Best Triplet: power 8.22, period 1.7097

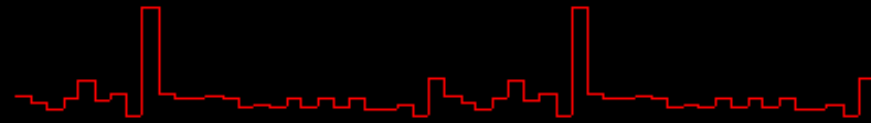


- Three evenly spaced spikes above 7.75X the mean power (1.9×10^{-25} W/m²) within 1 beam crossing time.

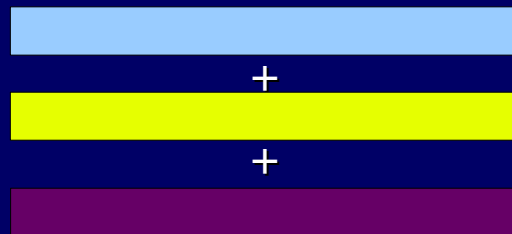


Pulses

Best Pulse: power 1.20, period 0.3555, score 1.01



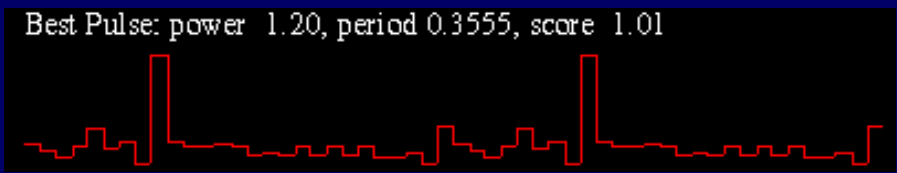
Folding:



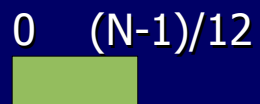
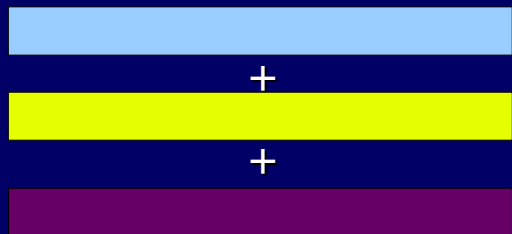
.... down to 2 bins at each step looking for items above threshold



Pulses



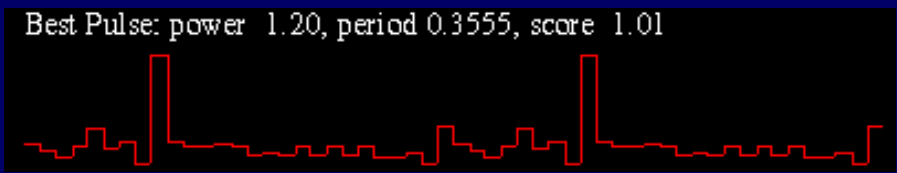
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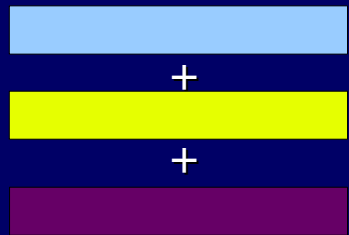
.... down to 2 bins at each step looking for items above threshold



Pulses



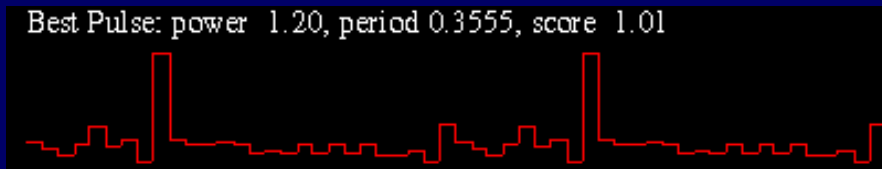
Folding:



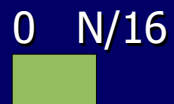
.... down to 2 bins at each step looking for items above threshold



Pulses



Folding:



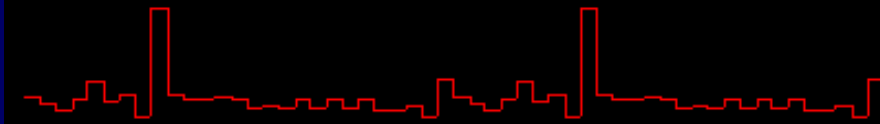
Periods searched:

- $[N/(3 \times 2^n)]$ to $[N/(4 \times 2^n)]$ in steps of $[1/(3 \times 2^n)]$ with $n=0-\log_2([N/3])-1$
- $[N/(4 \times 2^n)]$ to $[N/(5 \times 2^n)]$ in steps of $[1/(4 \times 2^n)]$ with $n=0-\log_2([N/4])-1$
- $[N/(5 \times 2^n)]$ to $[N/(6 \times 2^n)]$ in steps of $[1/(5 \times 2^n)]$ with $n=0-\log_2([N/5])-1$



Pulses

Best Pulse: power 1.20, period 0.3555, score 1.01



Threshold for folding:

Defining threshold based upon the variance doesn't work.

Statistics approach Gaussian at $n\sigma$ as number of samples per bin approaches n^2 .

So at 25σ , you need to add ~ 600 samples to a bin. Our samples per bin vary from 3 to 20480.

Fortunately basic math still works.

$$P(>T) = mQ(n,T)$$

where m =size of the folded array, n =number of samples per bin in the folded array, T =threshold and

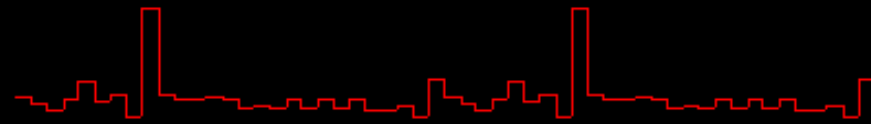
$$Q(n,T) = 1/\Gamma(n) \int_0^T e^{-t} t^{n-1} dt$$

Just invert Q to get T for a constant probability

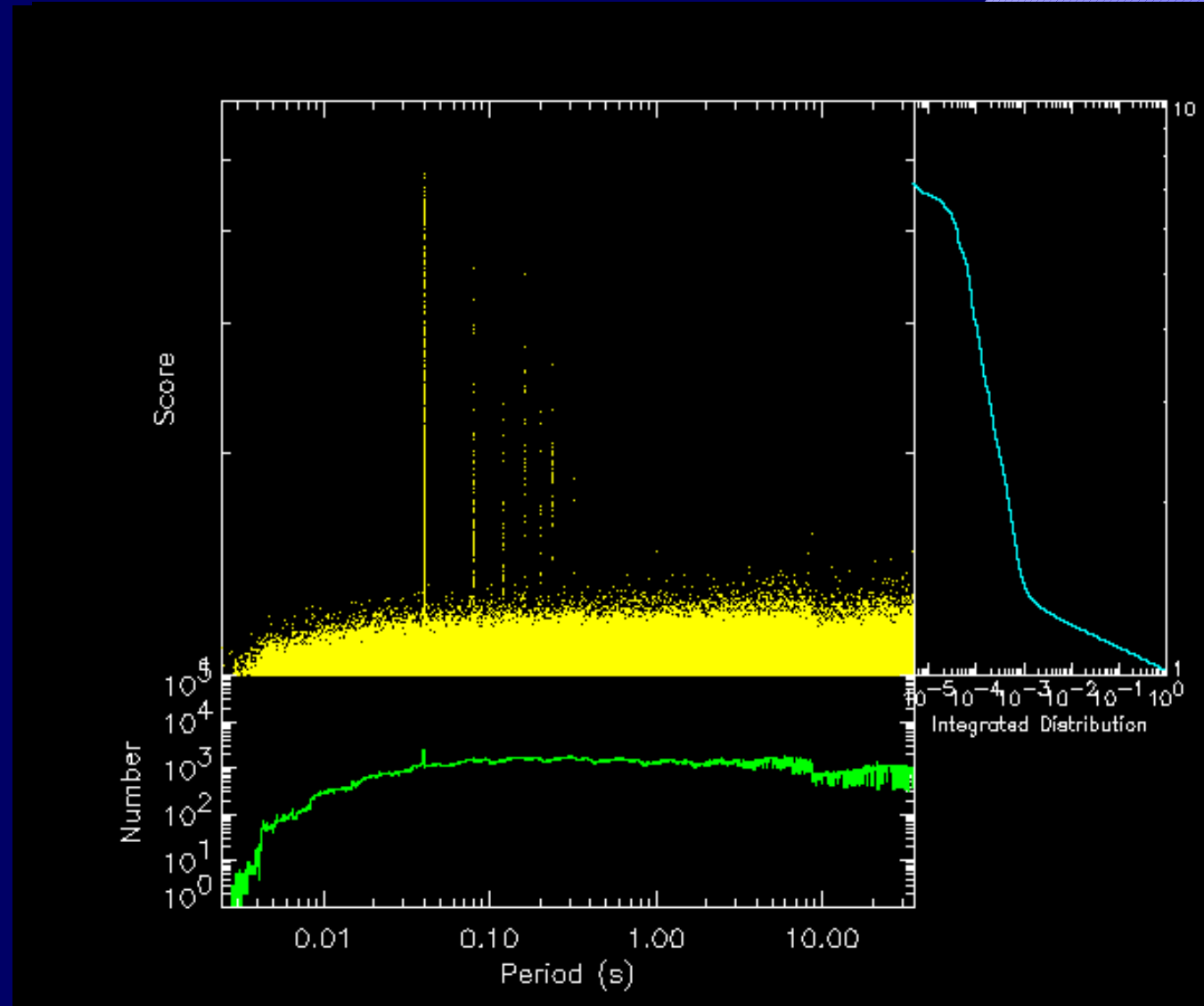


Pulses

Best Pulse: power 1.20, period 0.3555, score 1.01

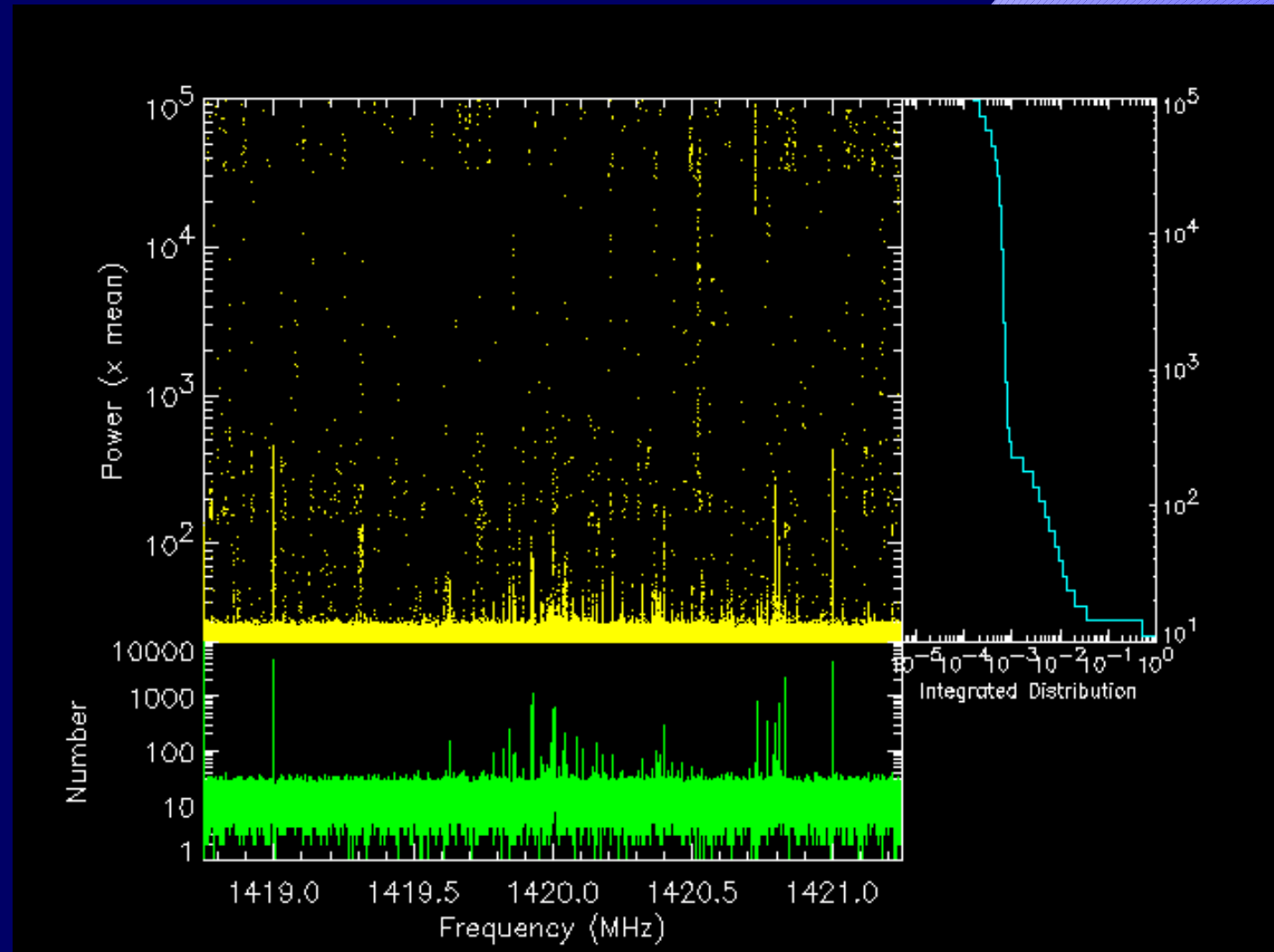


- Modified Fast folding algorithm w/ dynamic threshold
- Logarithmically spaced periods from 3ms to 35s
- Sensitivity as low as 2.5×10^{-27} J/m²

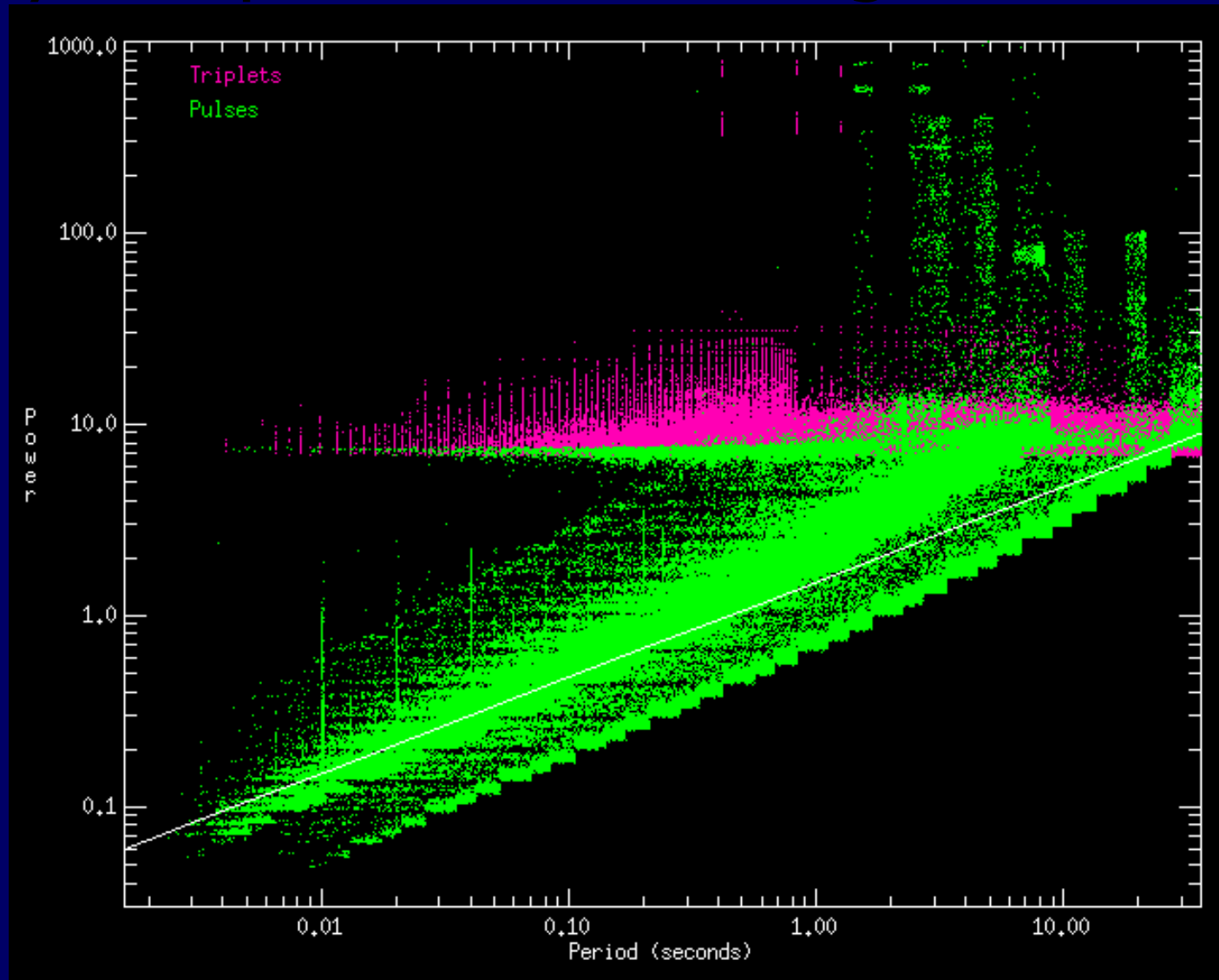


Spikes

- Power distribution in the Fourier transformed data is exponential if no RFI.
- SPIKE: Any bin in the spectrum above 25X the mean power (2.2×10^{-25} W/m²)



Why two pulse detection algorithms?



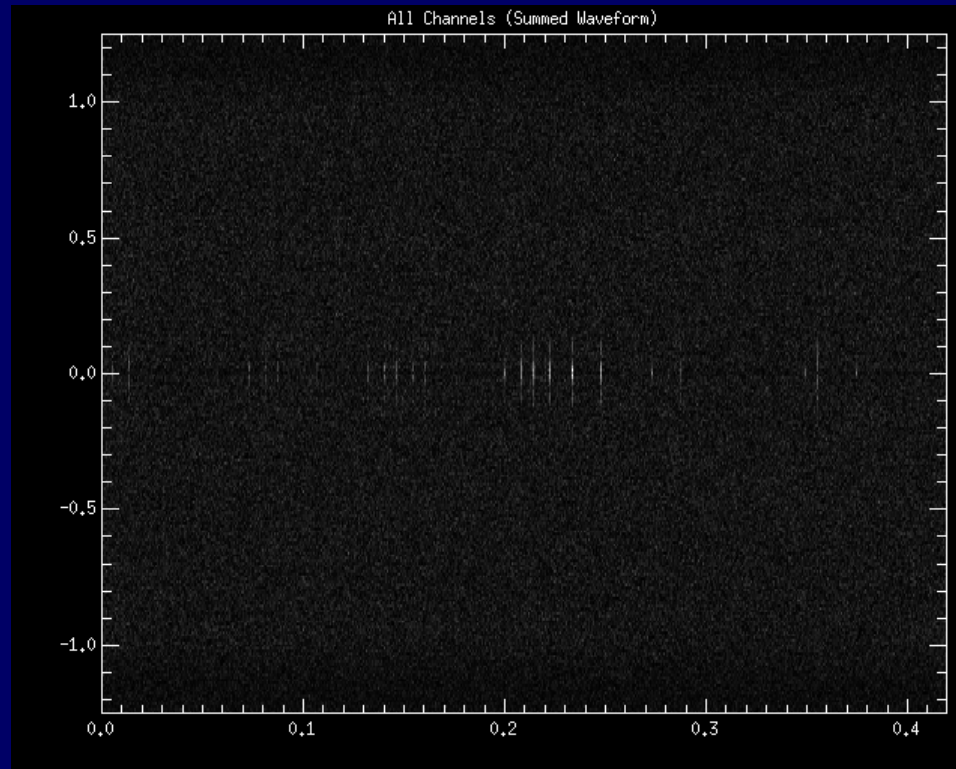
RFI Removal

- **RFI:**
 - Persistent over time
 - Not stable in sky coordinates
 - Can be drifting in frequency
- **RFI Removal:**
 - Zone RFI removal
 - Remove frequency or period ranges in a given time interval
 - Chirped RFI
 - If power is high it will be detected as frequency stable in low resolution spectra
 - If chirp is linear over long enough time it can be identified
 - If chirp is non linear other techniques need to be developed (work in progress)



RADAR

Wasn't a problem on the less sensitive flat feed.



Renders our data unusable if not corrected



RADAR

- Hardware radar blanking signal
 - Only blanks the most powerful radar.
 - Sometimes misses even that.
- Software radar blanking (in development)
 - Can blank the other 6 radars we see
 - Convolves data with the radar patterns to determine which patterns are seen, then generates file of time offsets to blank.
 - Can be use to recover data from before we recorded the hardware blanking signal.



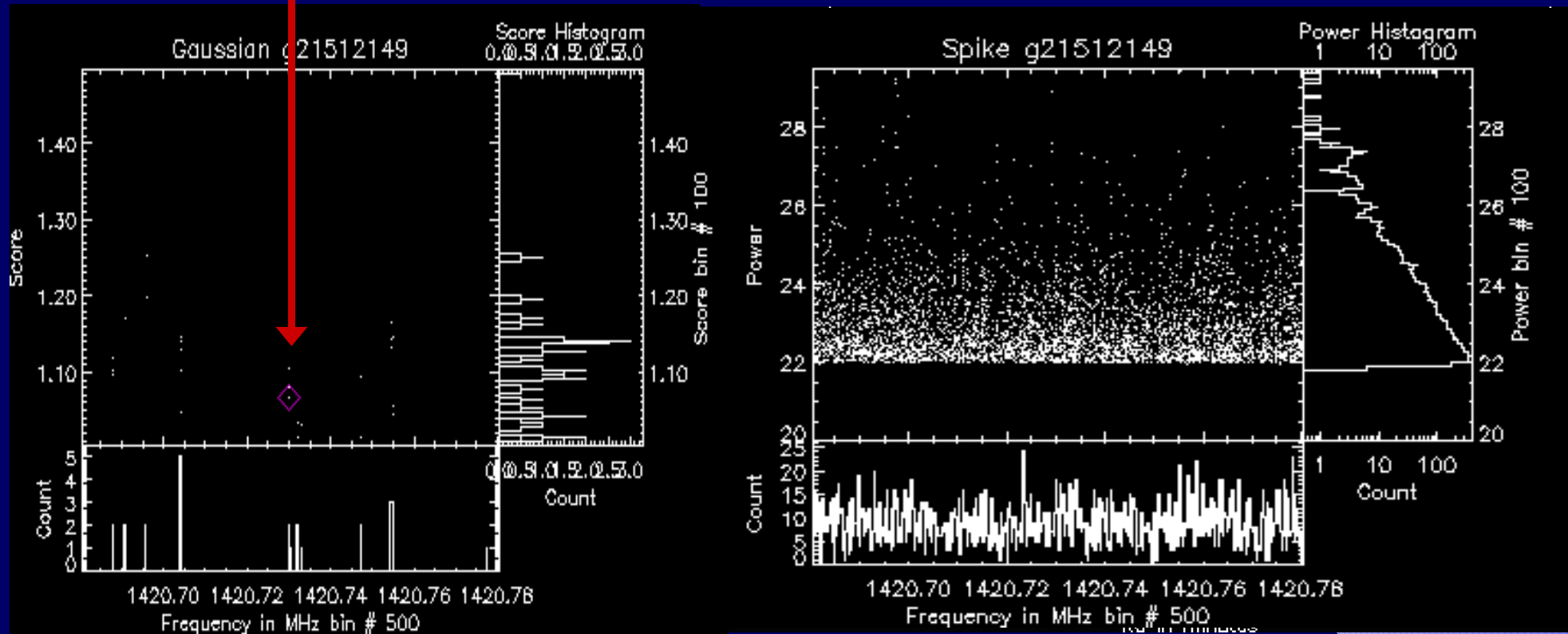
Candidate Identification

- **Candidate:** A signal or group of signals
 - Within a positional window (~ 1 beamwidth typ.)
 - Within a frequency window (variable)
 - Above a score or power threshold (variable)
 - With time separation \gg typical transient RFI timescale
- **Score:**
 - Relative ranking of a candidate's probability of arising due to random noise.
 - Should be independent of signal type
 - Can also include probability of coincidence /w celestial objects

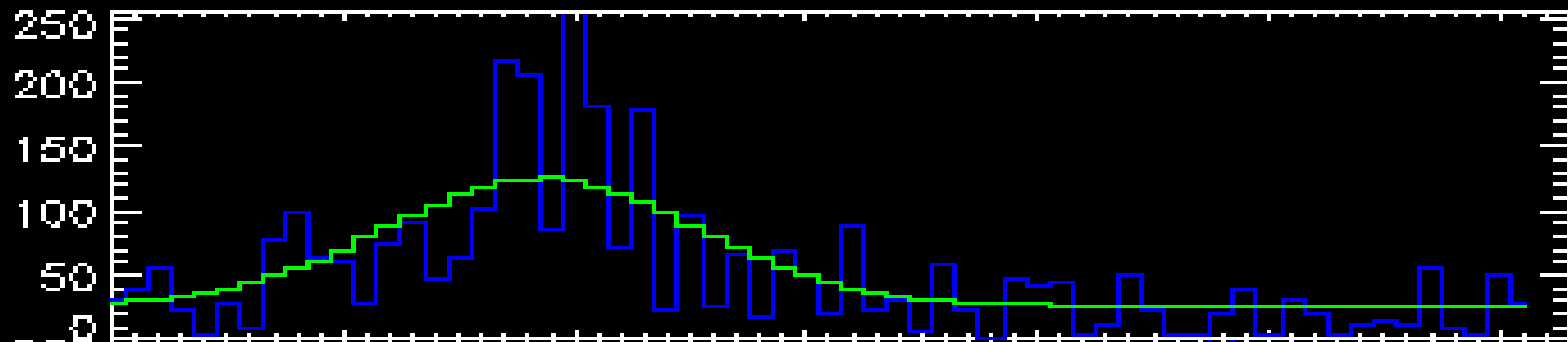


Gaussian Candidates

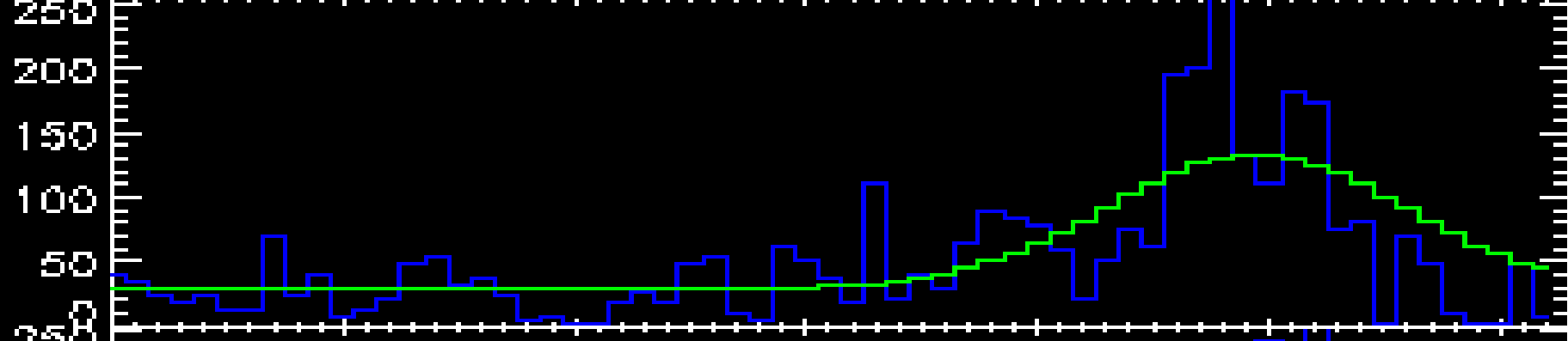
Likely RFI



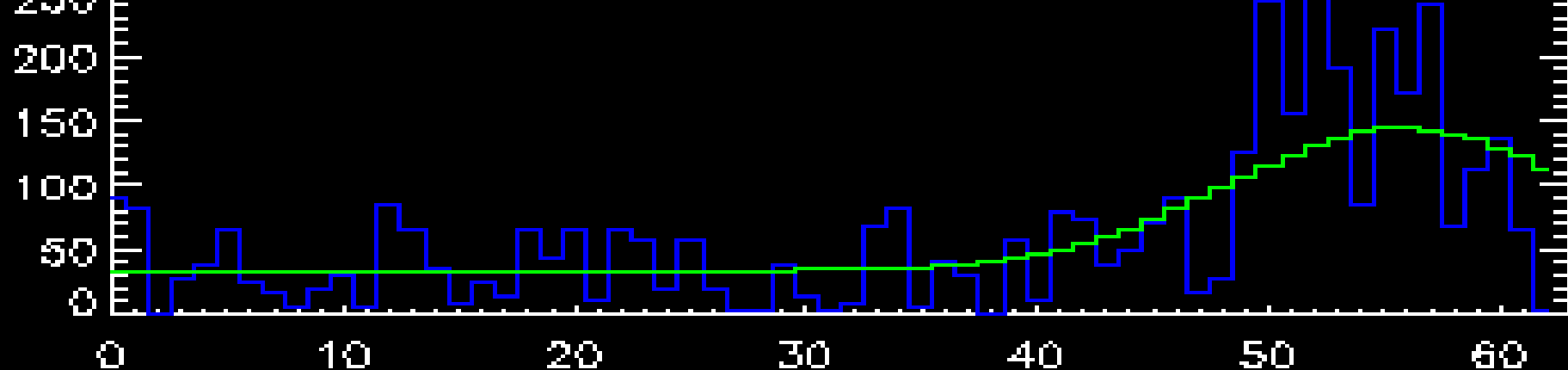
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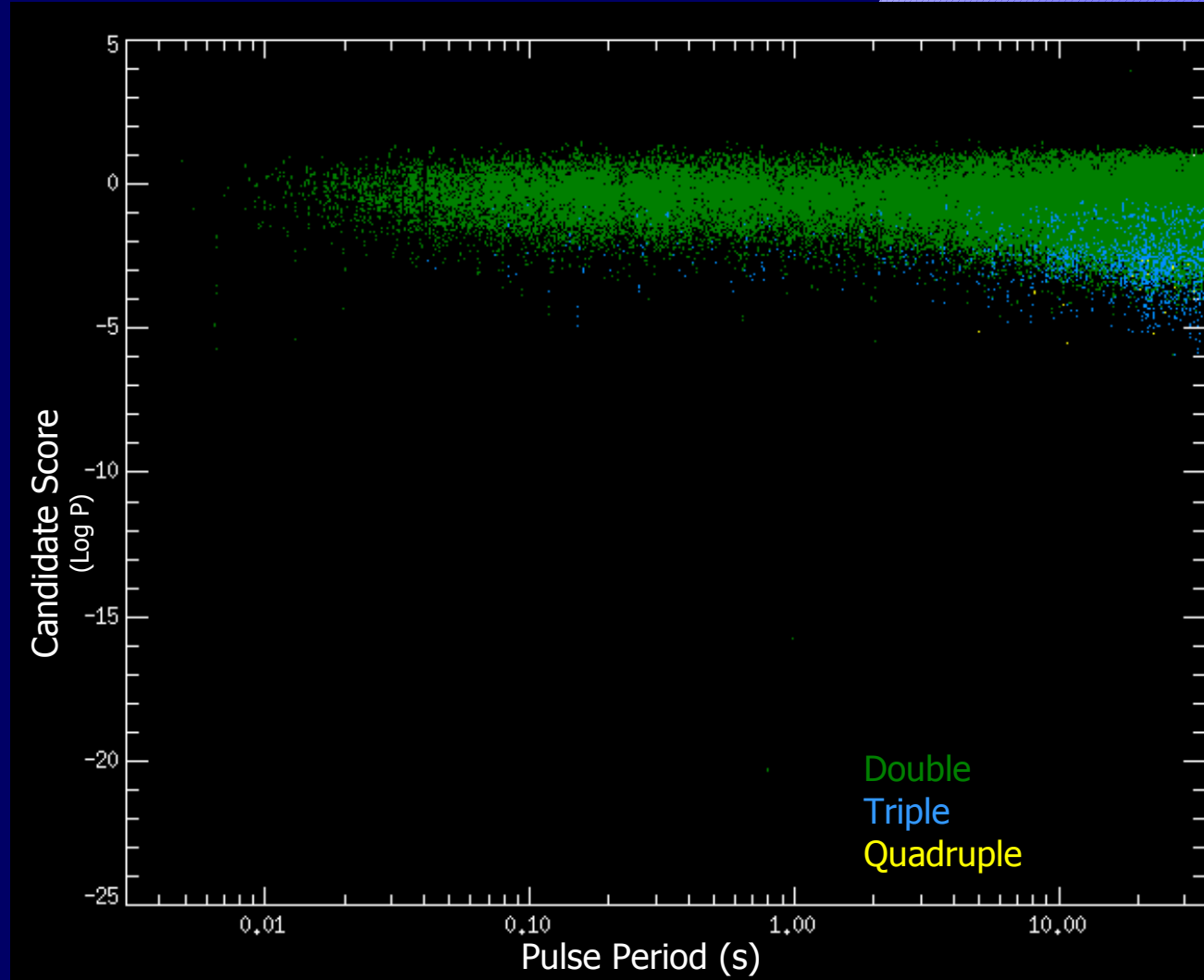
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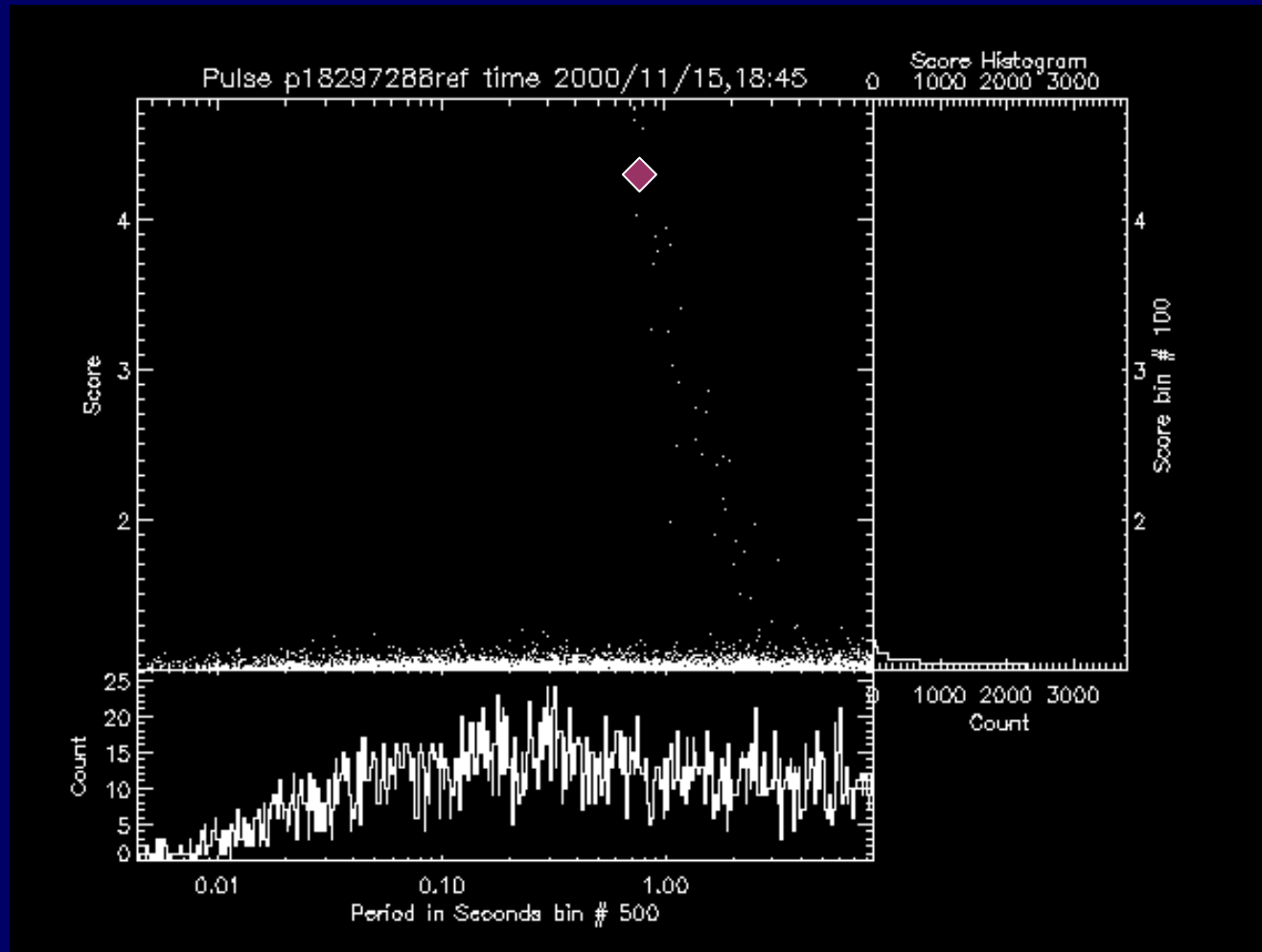
Gaussian Profile

Pulse Candidates

250k Candidates



Example Pulse Candidate



Pipeline and Reobservation

- Used to run candidate identification rarely
 - NTPCkr
- Feb 2003, reobserved the 200 best candidates we had at the time.
 - Only one candidate improved in score.



Mysterious signals from light years away

19:00 01 September 2004 by [Eugenie Samuel Reich](#)

[Read full article](#)

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In February 2003, astronomers involved in the search for extraterrestrial intelligence (SETI) pointed the massive radio telescope in Arecibo, Puerto Rico, at around 200 sections of the sky.

The same telescope had previously detected unexplained radio signals at least twice from each of these regions, and the astronomers were trying to reconfirm the findings. The team has now finished analysing the data, and all the signals seem to have disappeared. Except one, which has got stronger.

This radio signal, now seen on three separate occasions, is an enigma. It could be generated by a previously unknown astronomical phenomenon. Or it could be something much more mundane, maybe an artefact of the telescope itself.

But it also happens to be the best candidate yet for a contact by intelligent aliens in the nearly six-year history of the SETI@home project, which uses programs running as screensavers on millions of personal computers worldwide to sift through signals picked up by the Arecibo telescope.

Absorb and emit

"It's the most interesting signal from SETI@home," says Dan Werthimer, a radio astronomer at the University of California Berkeley (UCB) and the chief

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30 Trillion Fruitless Tries

But scientists keep searching for extraterrestrial intelligence

By Charles Petit
Chronicle Science Writer

Astronomers in Berkeley, hoping to be the first earthlings to detect signals from alien civilizations, said they have in one year accumulated a success rate of approximately zero for 30 trillion.

"I think it is going to be a long search for everybody," said Stuart Bowyer, an astronomer from the University of California at Berkeley and leader of one of the more ambitious Search for Extraterrestrial Intelligence (SETI) projects under way worldwide.

The Berkeley program is called SERENDIP III. It was started one year ago by piggybacking on signals being gathered for other projects by astronomers using the 1,000-foot-wide Arecibo Radio Telescope in Puerto Rico.

The extravagantly contrived acronym stands for Search for Extraterrestrial Radio Emissions from Nearby Intelligent Populations. It is the third such program in 15 years at Berkeley but has a sensitivity many times better than earlier ones.

A sophisticated electronics system studies a portion of the radio spectrum, between 434 and 436 megahertz, not far from those used for television and some radar. It monitors 4 million channels within that portion of the spectrum, repeating the analysis every 1.7 seconds. In the 3,600 hours of operation so far, nothing definite has turned up.

However, said Chuck Donnelly, project software director, the electronics automatically keep a running list of 100 or so of the most peculiar signals for further analysis. At the moment, the list of "candidates" stands at 104.

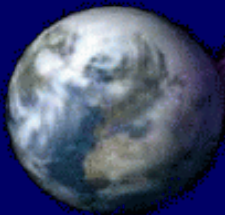
Chances are, Bowyer said, that like all the thousands of previous candidates rejected, the candidates will turn out to be stray signals from airplanes, someone's washing machine, or just the natural "burp" of a distant star.

Within the hiss of natural radio emanations from stars and colliding galaxies, scientists hope to pick up the pure tones or tightly tuned signals that may signal an intelligence out there.

The Berkeley SETI scientists presented their first year's report as part of the meeting on campus of the American Astronomical Society. Other major SETI projects include one managed by the NASA Ames Research Center and the Jet Propulsion Laboratory that looks for signals much more powerful than those detectable by the Berkeley group.

"We are looking for the leakage of radio or TV signals from some other civilization," Bowyer said. Just as Earth's radar signals have been spreading outward for 50 years — with TV shows such as "I Love Lucy" reaching tens of thousands of stars — corresponding signals from far away may be washing over Earth. "It just is not so easy to find them," Bowyer said.

Now 10^{23} Fruitless Tries



SETI@home

The Search for Extraterrestrial Intelligence



AstroPulse (Search for broadband μs pulses)

Josh von Korff

Signal types:

- Single pulses
- Repeating pulses (fast folding)
- Microsecond to millisecond scale (broadband)

Possible sources:

- ETI
- Extragalactic transient pulses
- Primordial (10^{15}) g black holes, exploding due to Hawking radiation
- Repeating signals from pulsars
- Giant pulses from pulsars
- RRATs (rotating radio transients)
- New phenomena



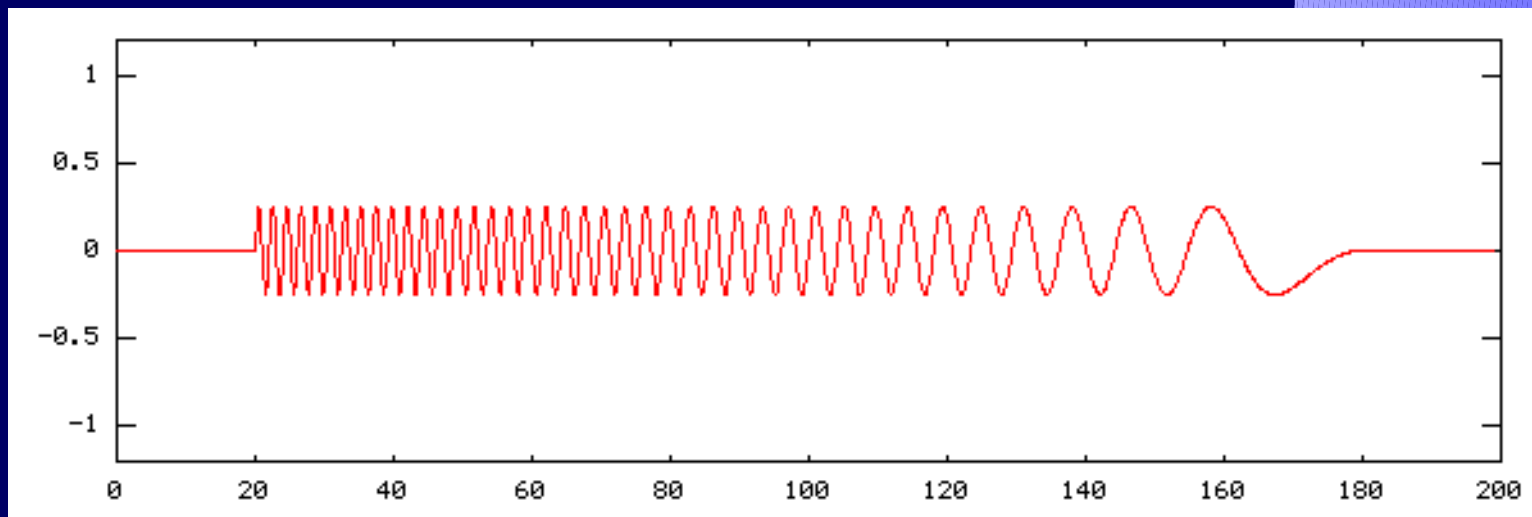
Astropulse motivation

- SETI projects have not searched for radio transient communications
- Exploding black holes have never been detected. Could confirm the theory of Hawking radiation & gain information about the early universe. Or, place limits on the rate of black hole explosions
- New binary pulsars could help test GR.
- New fast pulsars could help detect gravitational waves
- RRATs were recently discovered, and little is known about them
- Lorimer et al. extragalactic pulse is the only known pulse of its kind. We should be able to get statistical distributions of such pulses.



Parameter space: dispersion measure

Broadband signals are dispersed by the interstellar medium:



Coherent and incoherent dedispersion

Incoherent dedispersion:

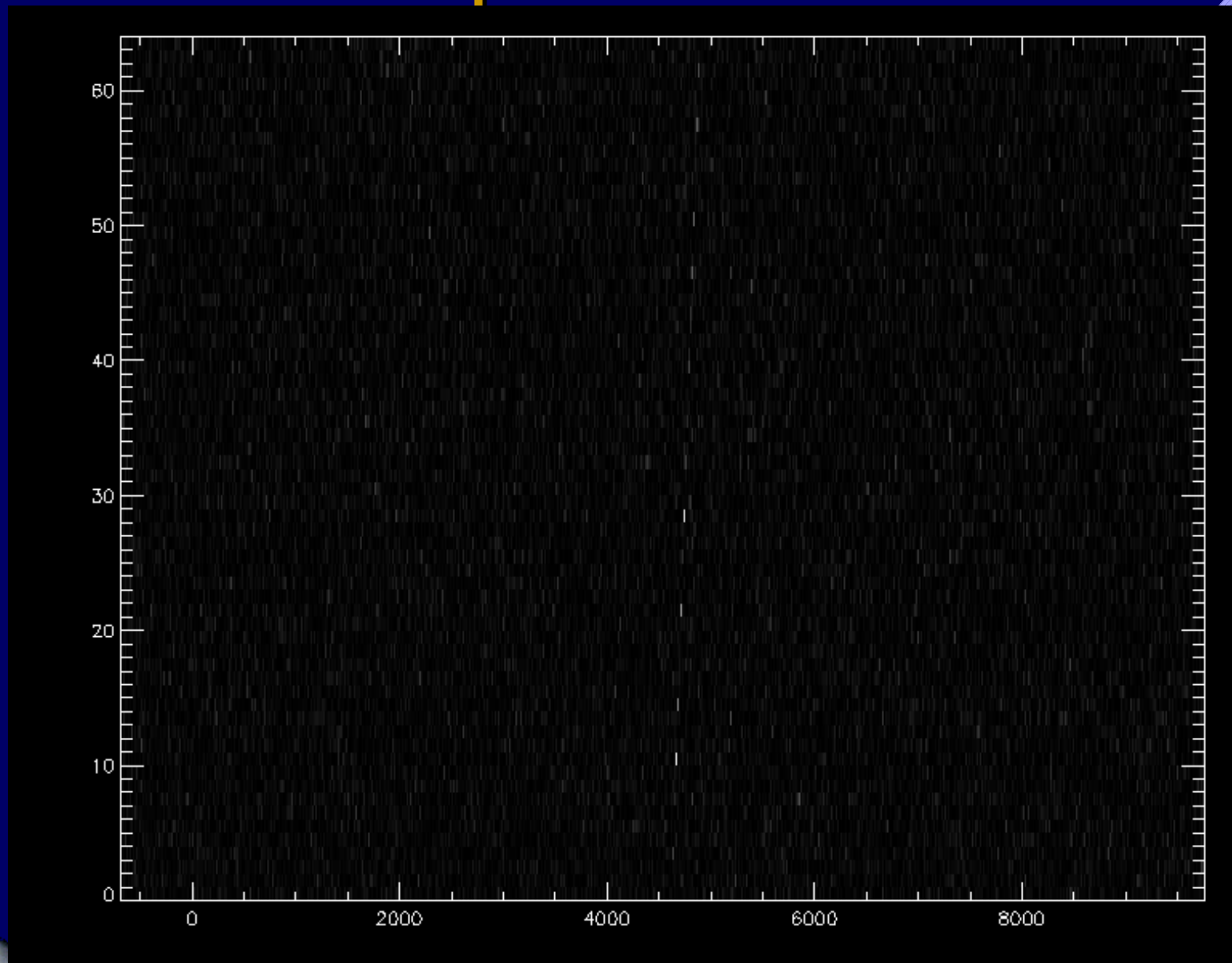
- Signal is broken into sub-bands, which are reassembled
- Practical limit of about 50 μ s time resolution @ $DM=1000 \text{ cm}^{-3} \text{ pc}$

Coherent dedispersion:

- Requires more computing power
- No numerical lower limit on time resolution.



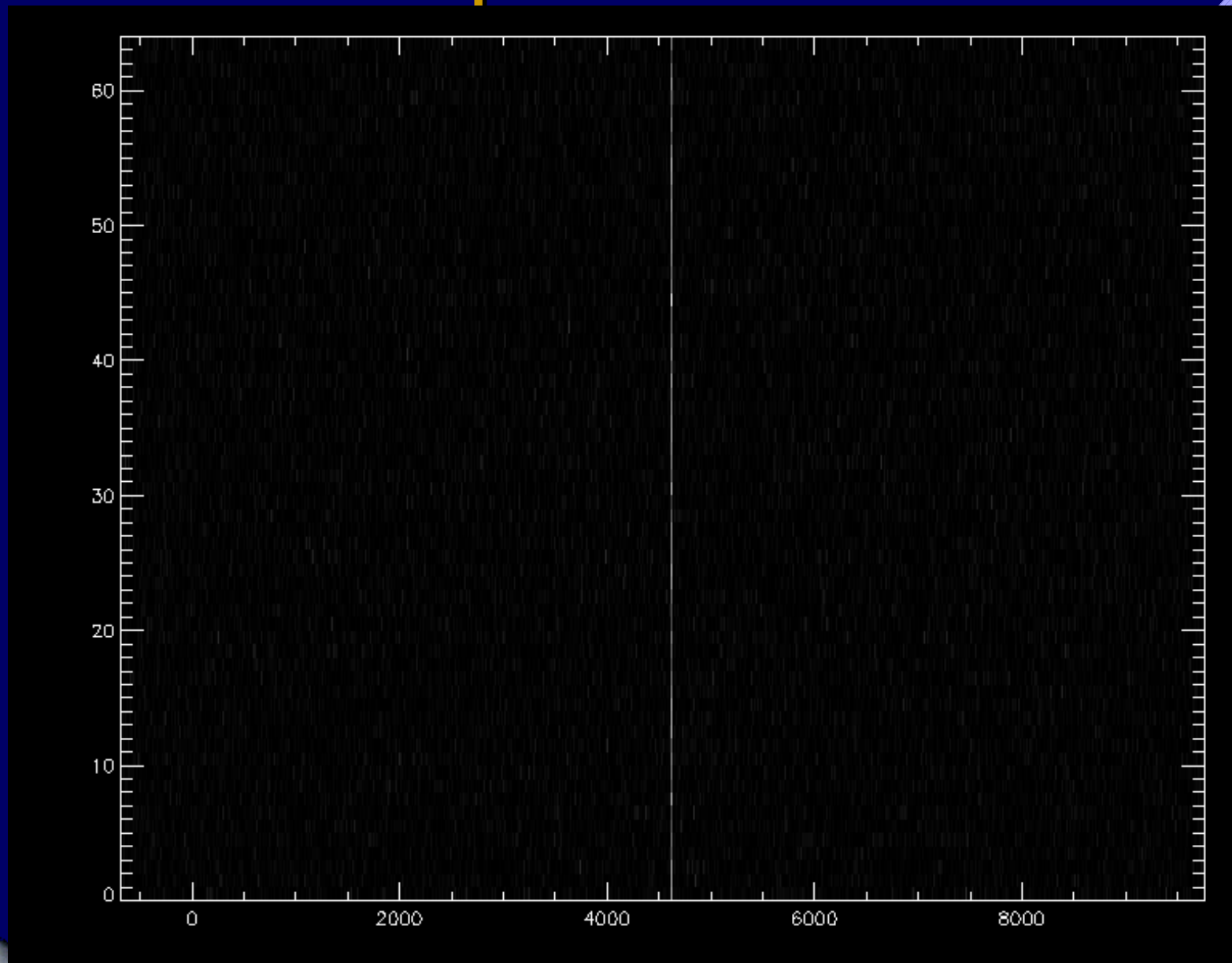
Coherent Dedispersion



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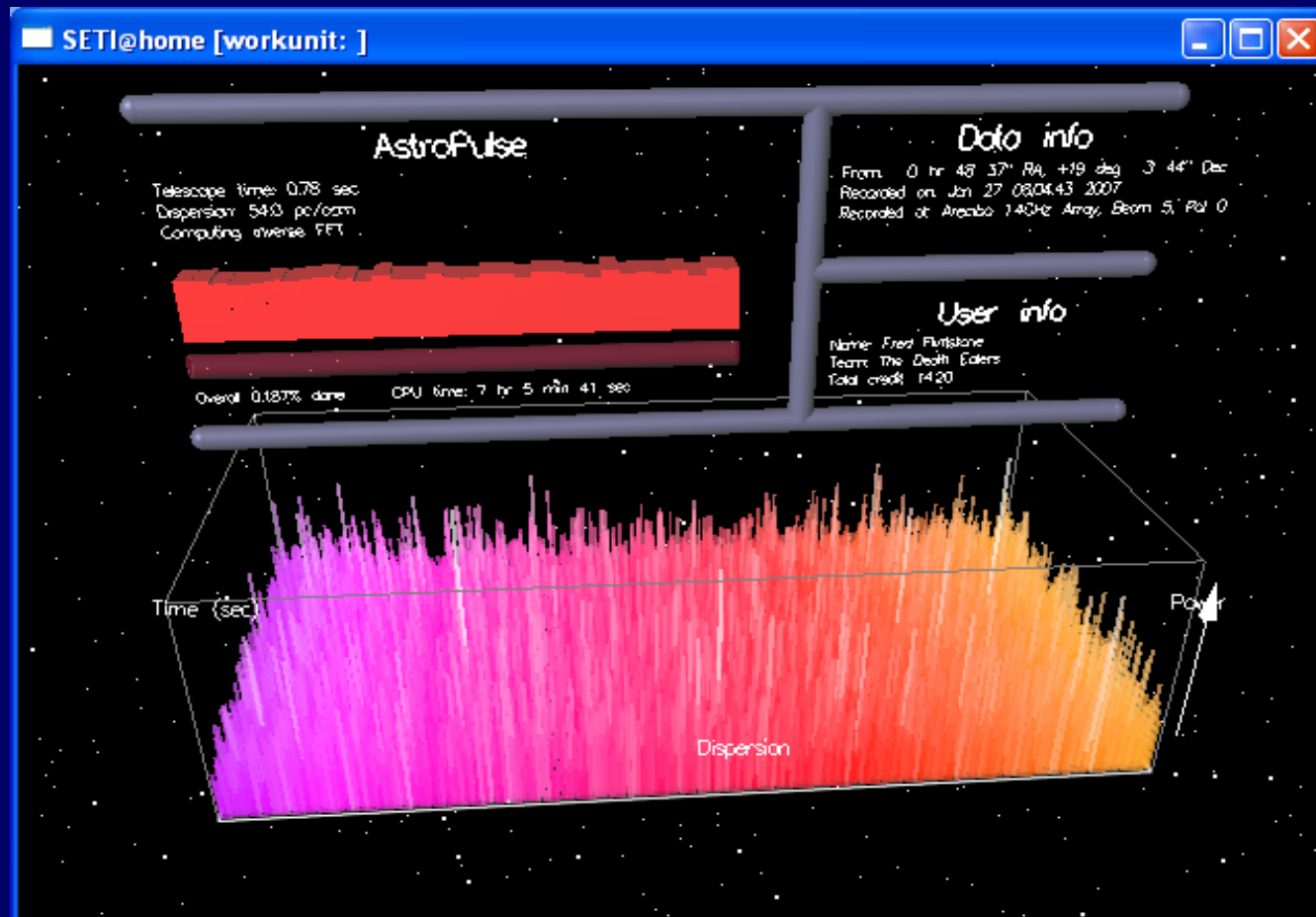
Coherent Dedispersion



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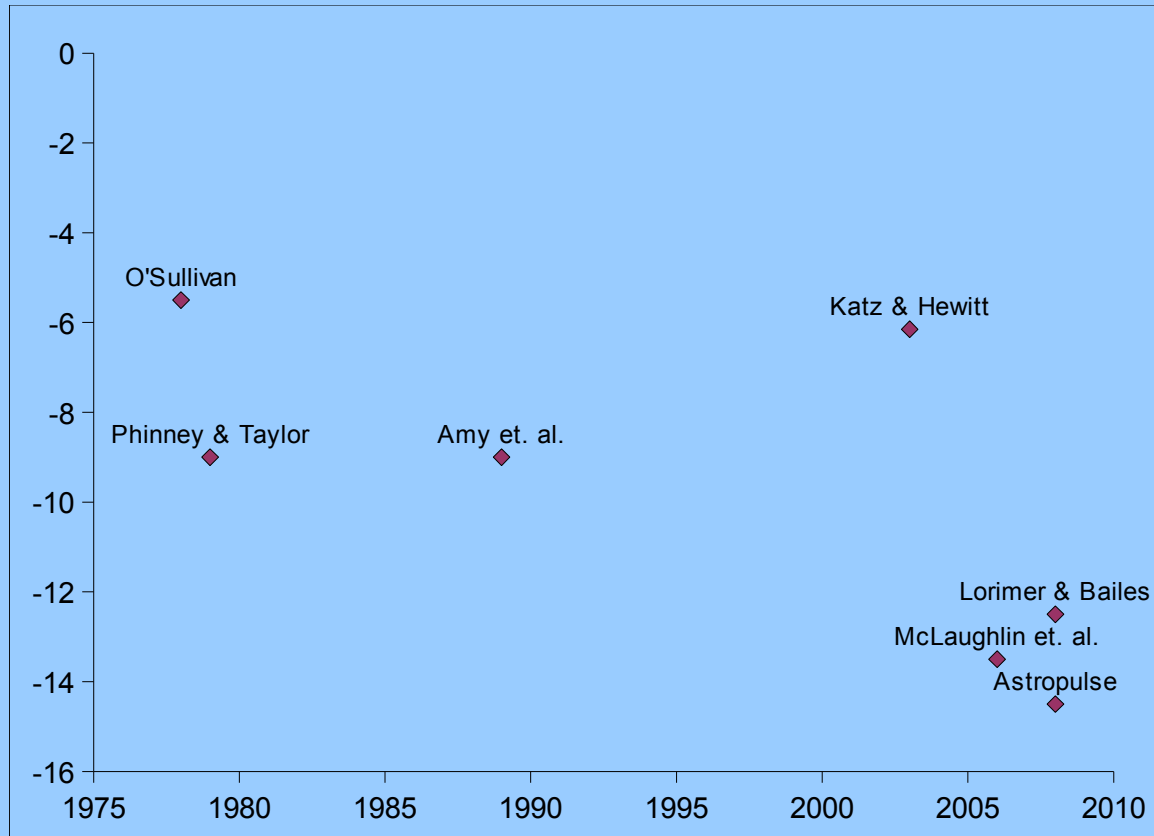
Astropulse client



... Astropulse has a different client program



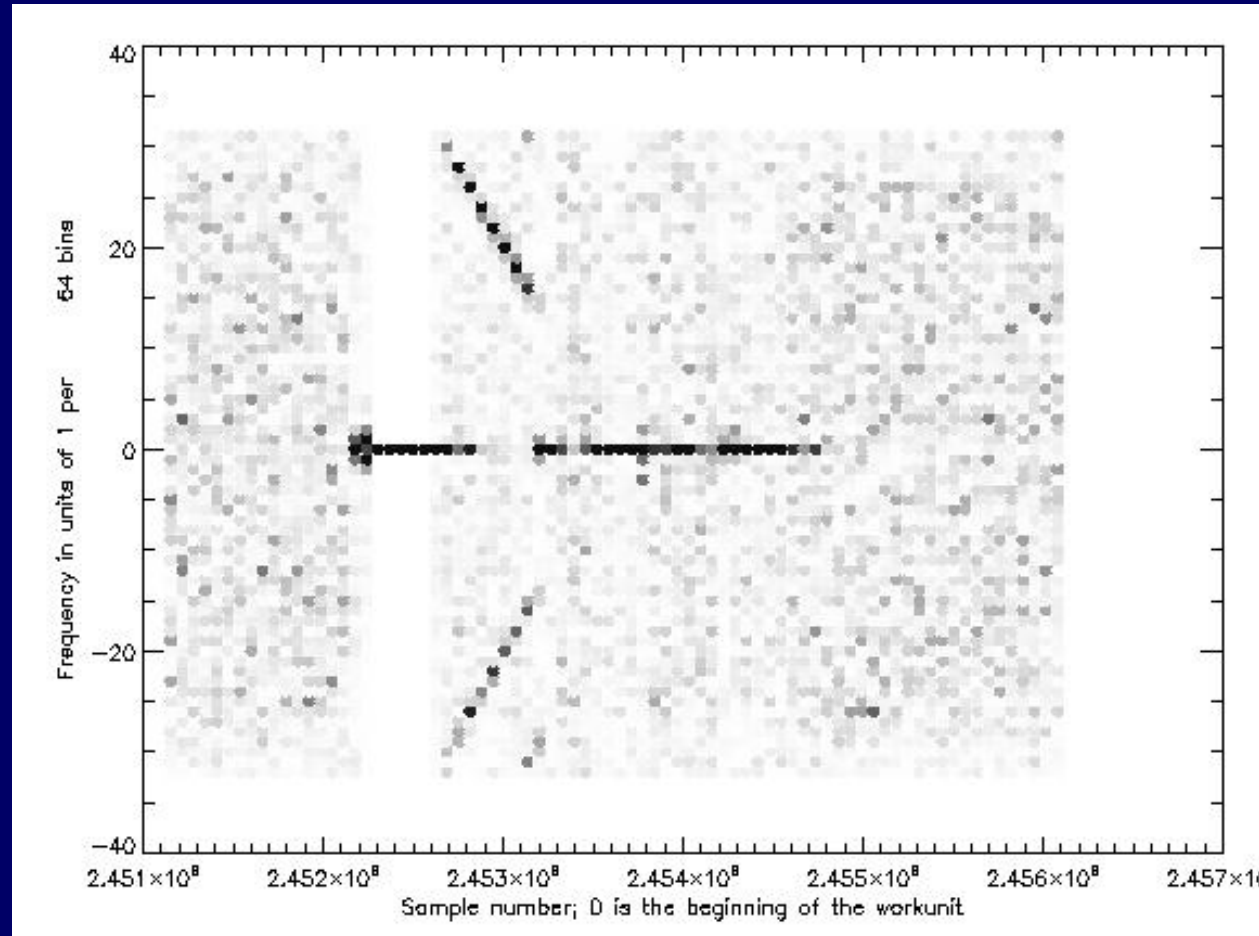
15x more sensitive than previous studies looking for exploding PBH



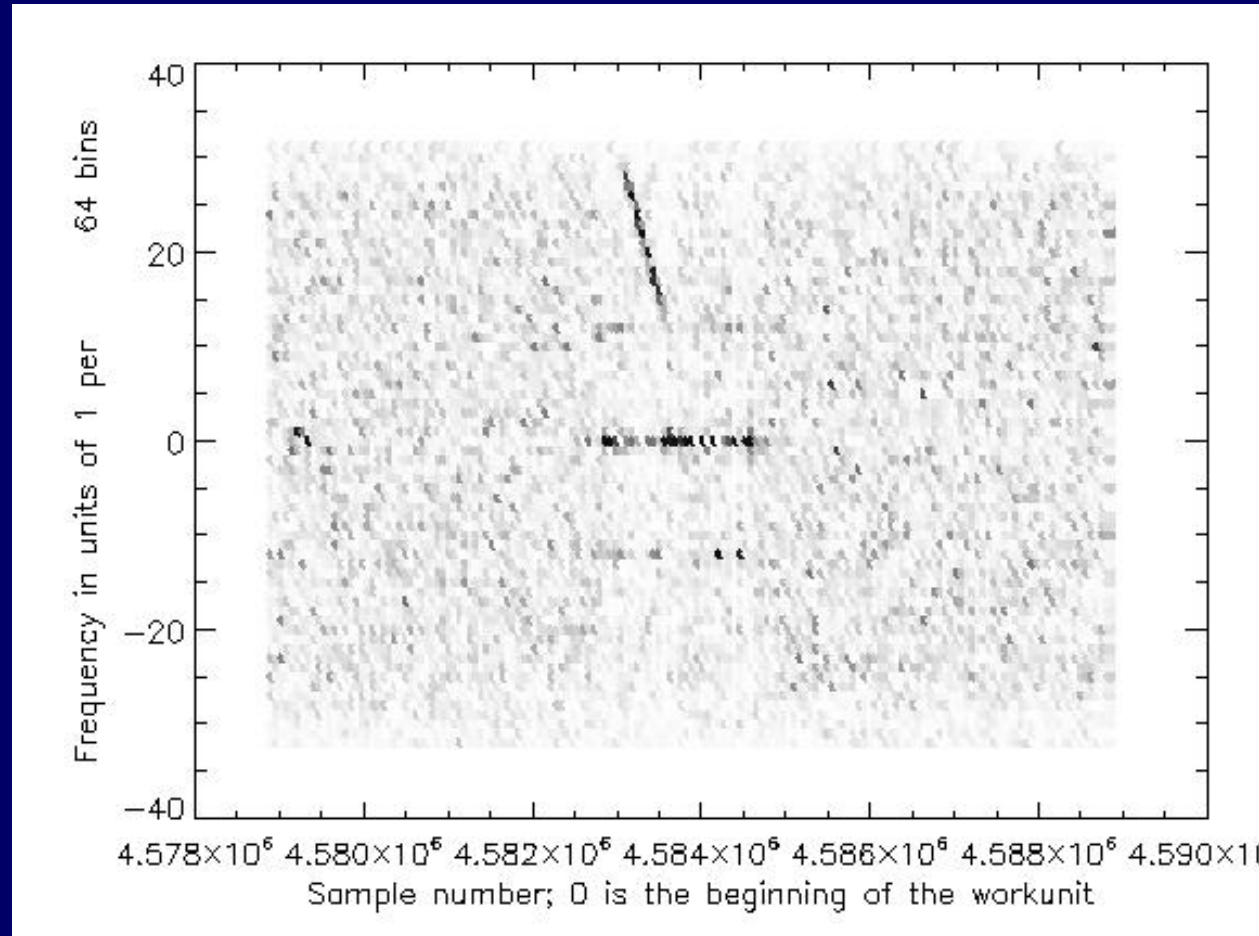
Phinney & Taylor, "A Sensitive Search for Radio Pulses from Primordial Black Holes and Distance Supernovae" Nature Vol. 277, 11 January 1979
O'Sullivan et. al. "Limits on Cosmic Radio Bursts With Microsecond Time Scales", Nature vol. 276, 7 December 1978
Katz & Hewitt 2003, "A Search for Transient Astronomical Radio Emission", Pub. Astr. Soc. Pac., 115:675-687, 2003 June
Amy, Large & Vaughan "A Search for Transient Events at 843 MHz", Proc. ASA 8 (2) 1989



Very sensitive to radar



Very sensitive to radar

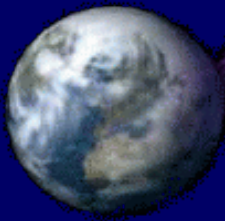
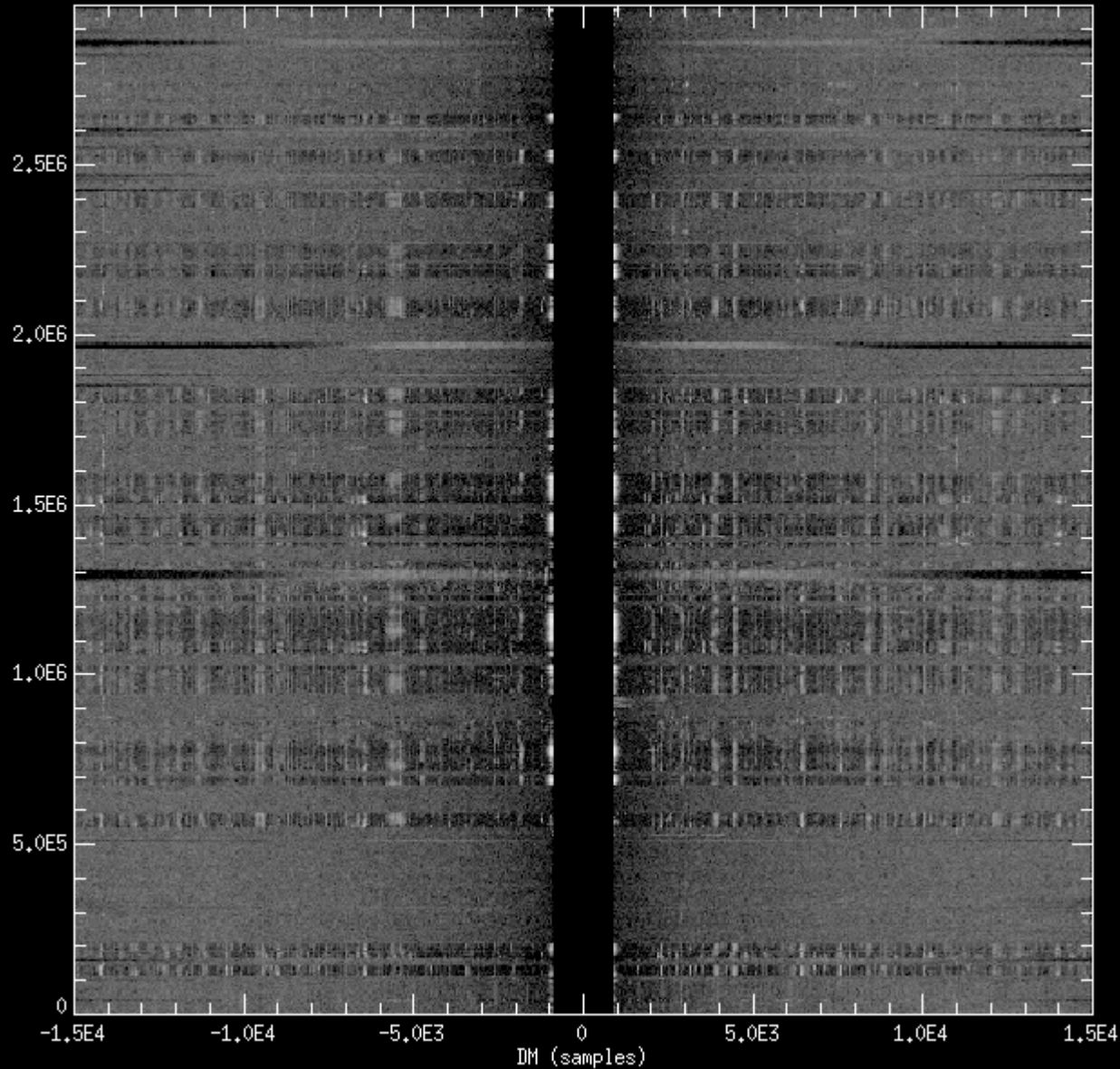


Radar Rejection

- Blanking Signal in Splitter
- Radar detection and blanking in the application
- Reject times when radar is bad (more than 5% of workunit is blanked due to radar).
- DM based rejection (same DM seen at different times on different parts of the sky).



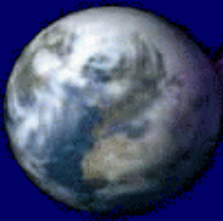
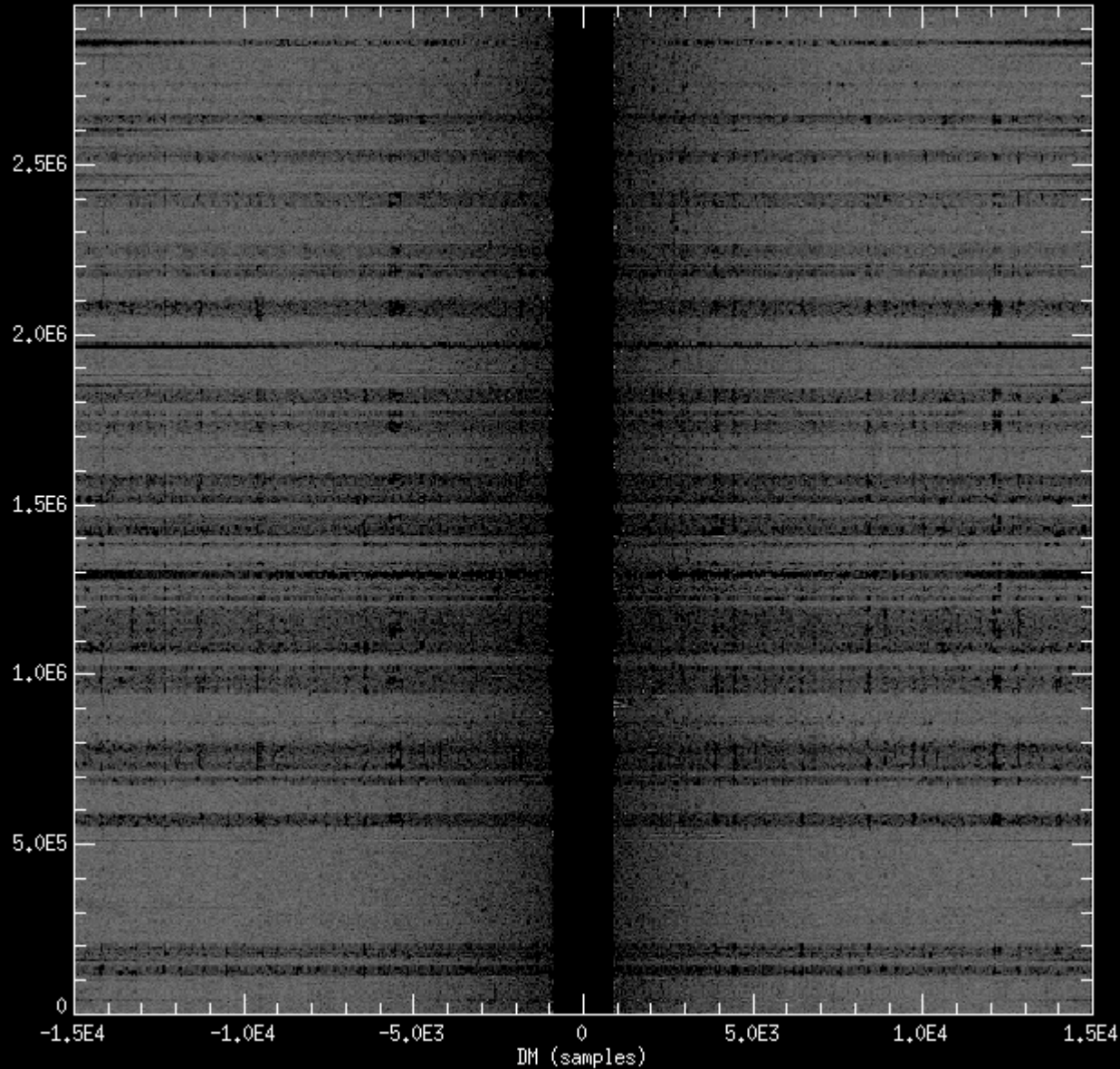
Radar Rejection



S
The Search for Extraterrestrial Intelligence



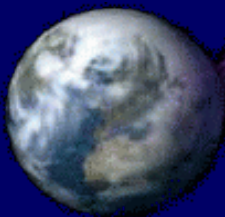
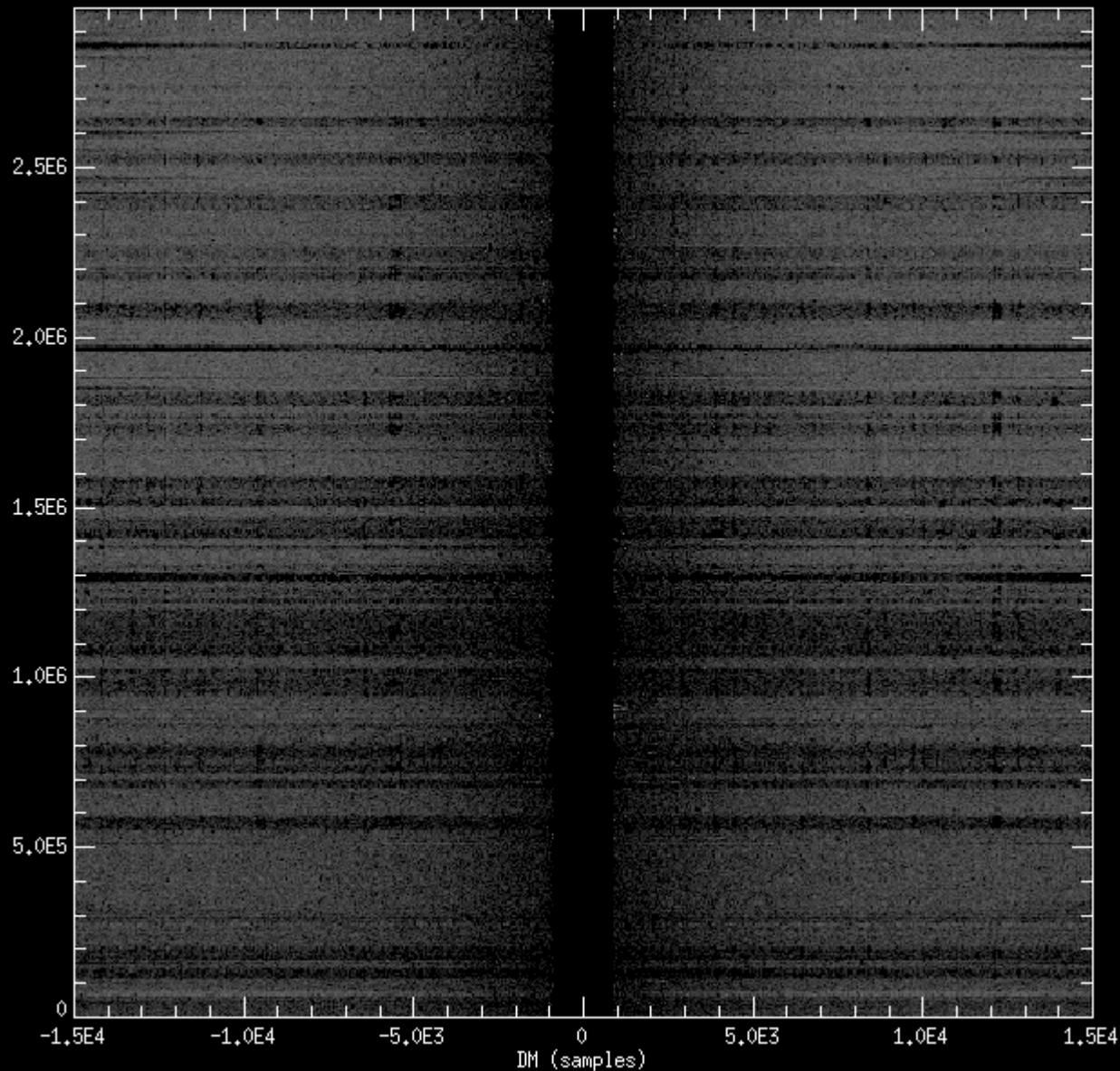
Radar Rejection



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Radar Rejection

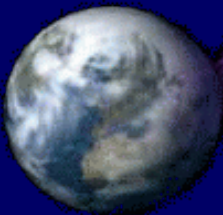
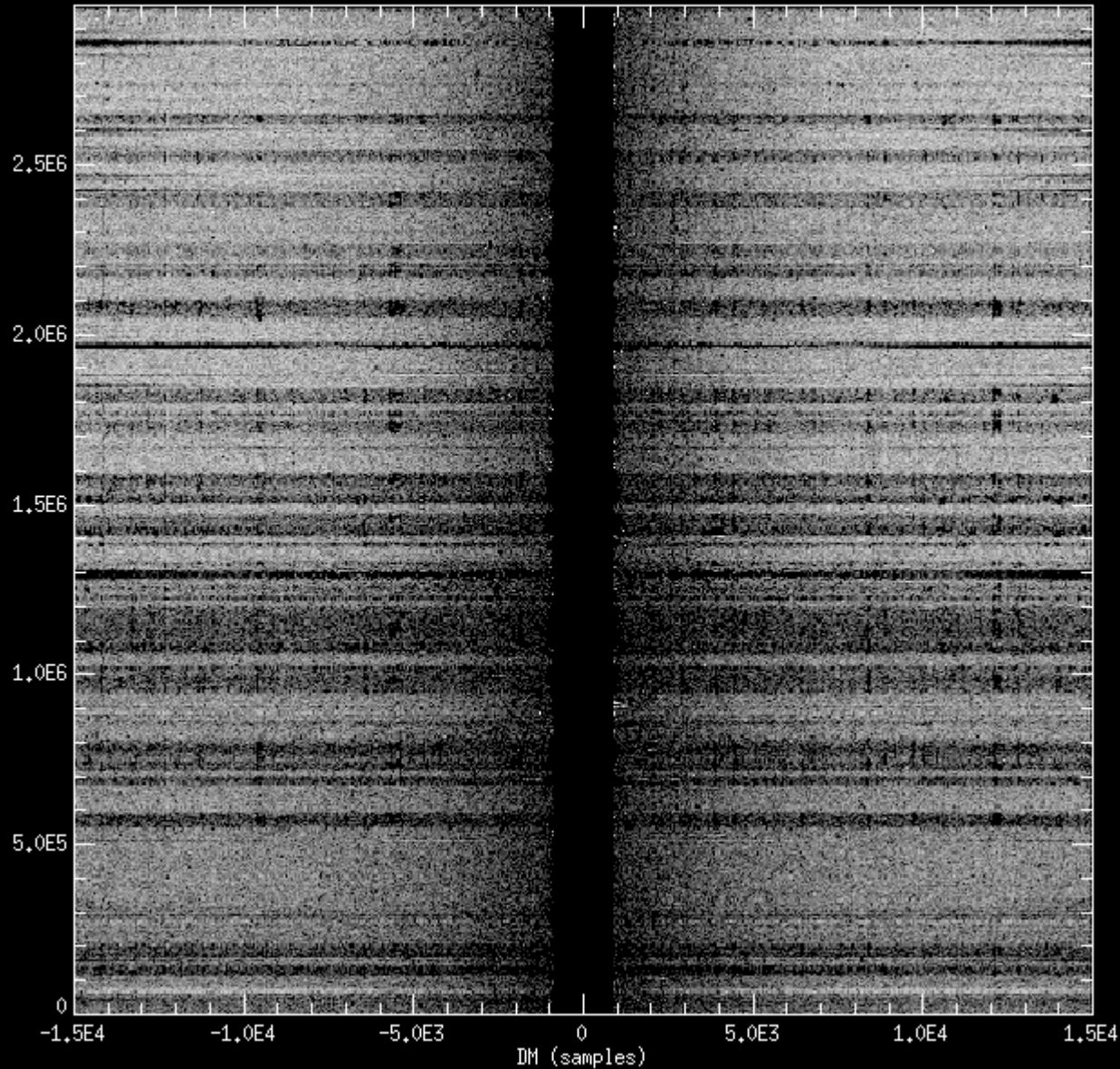


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Radar Rejection

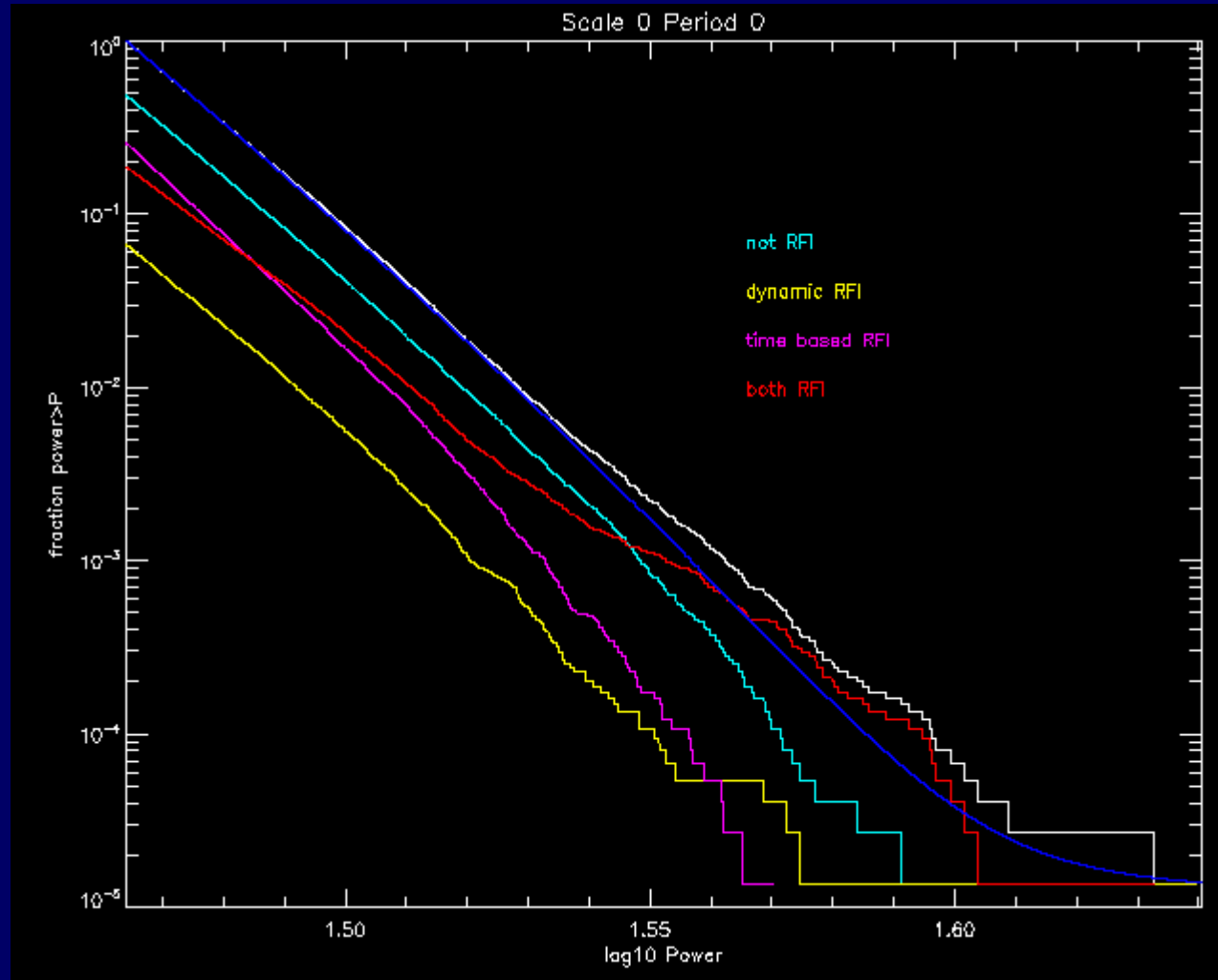


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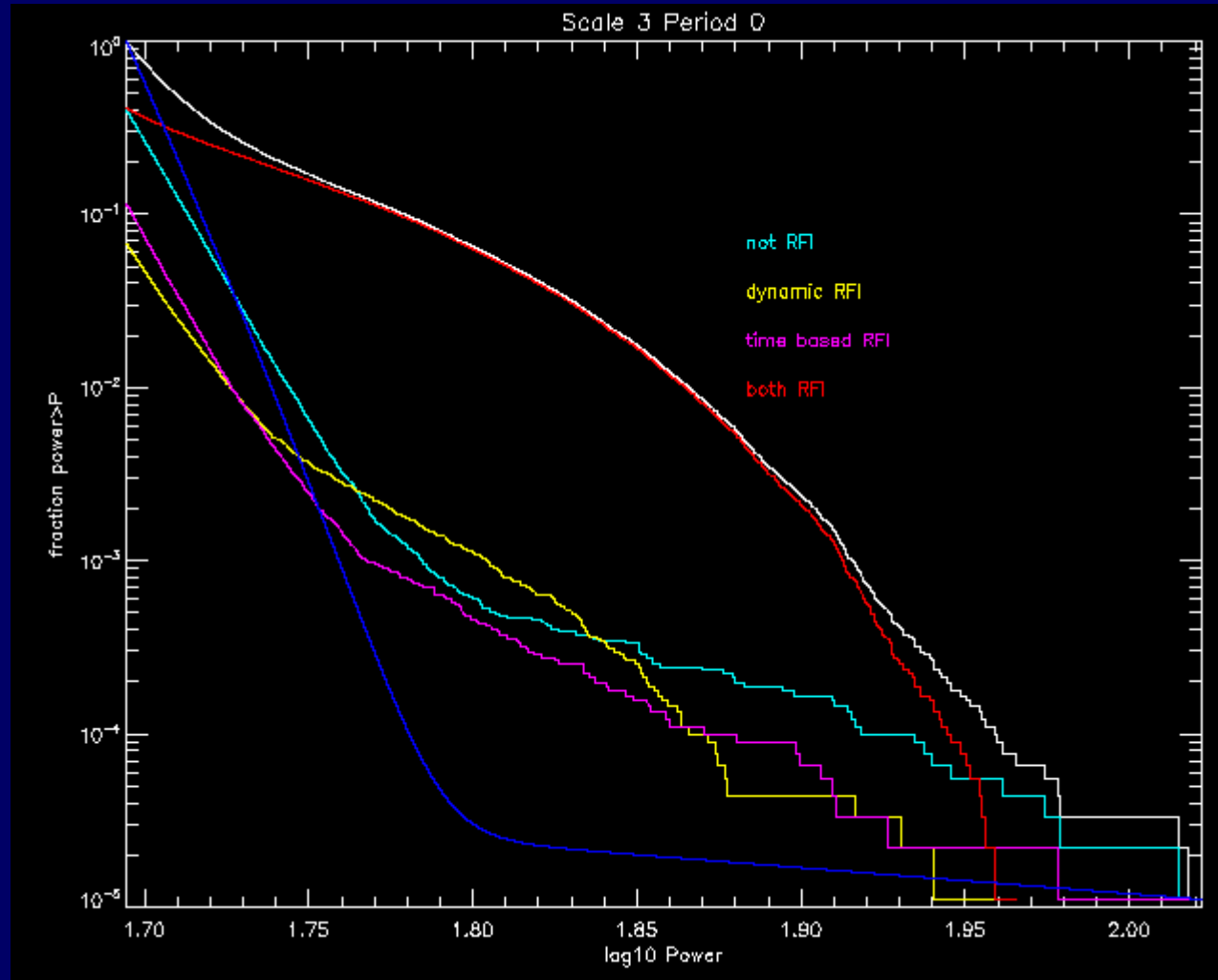
The Search for Extraterrestrial Intelligence



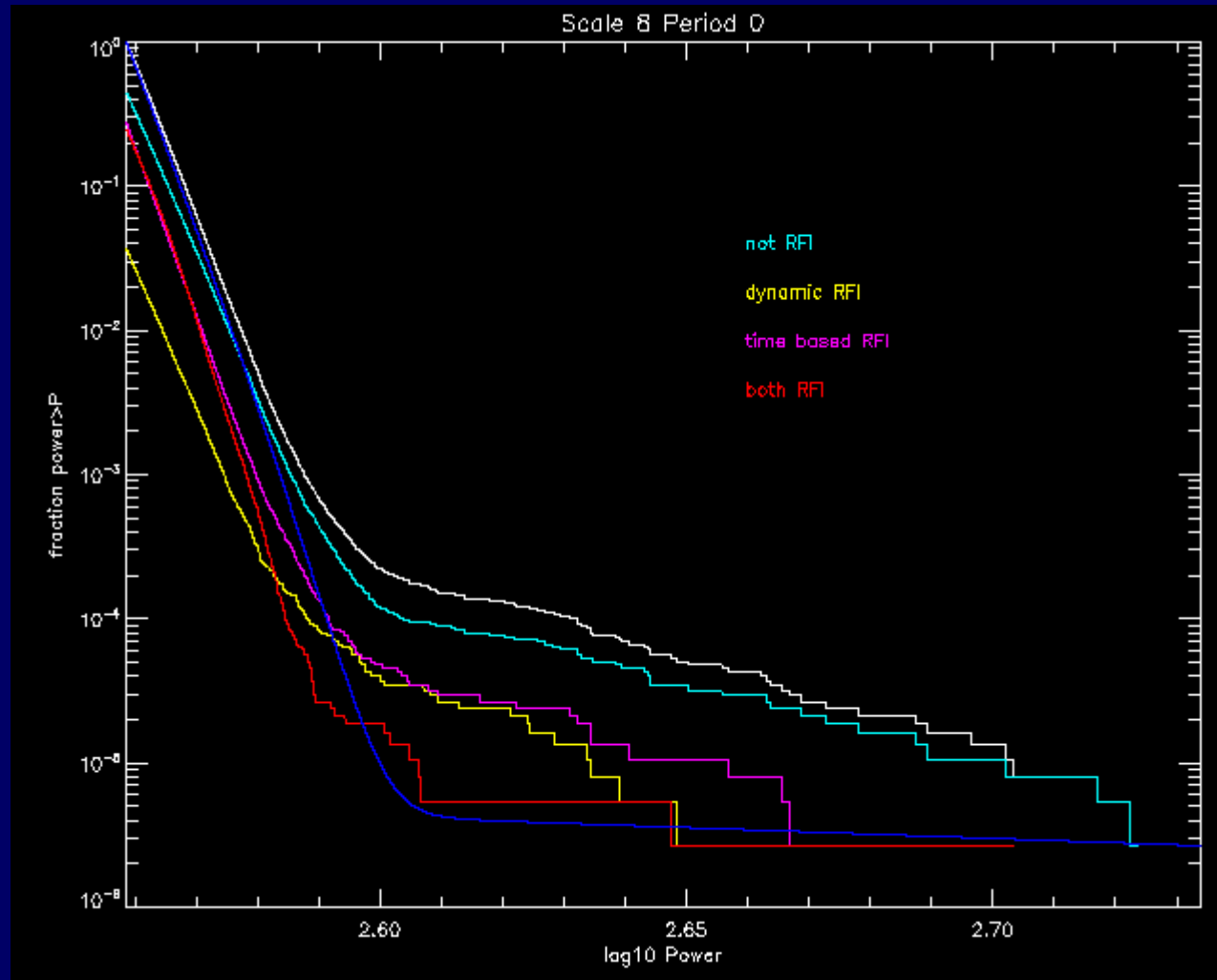
Radar Rejection



Radar Rejection



Radar Rejection



What's next?

- Frequency stepping.
- Wider band?
- Cross polarization analysis in client?
- New RFI rejection algorithms?
- Other telescopes?

