Observational Limit on Gravitational Waves from Binary Neutron Stars in the Galaxy

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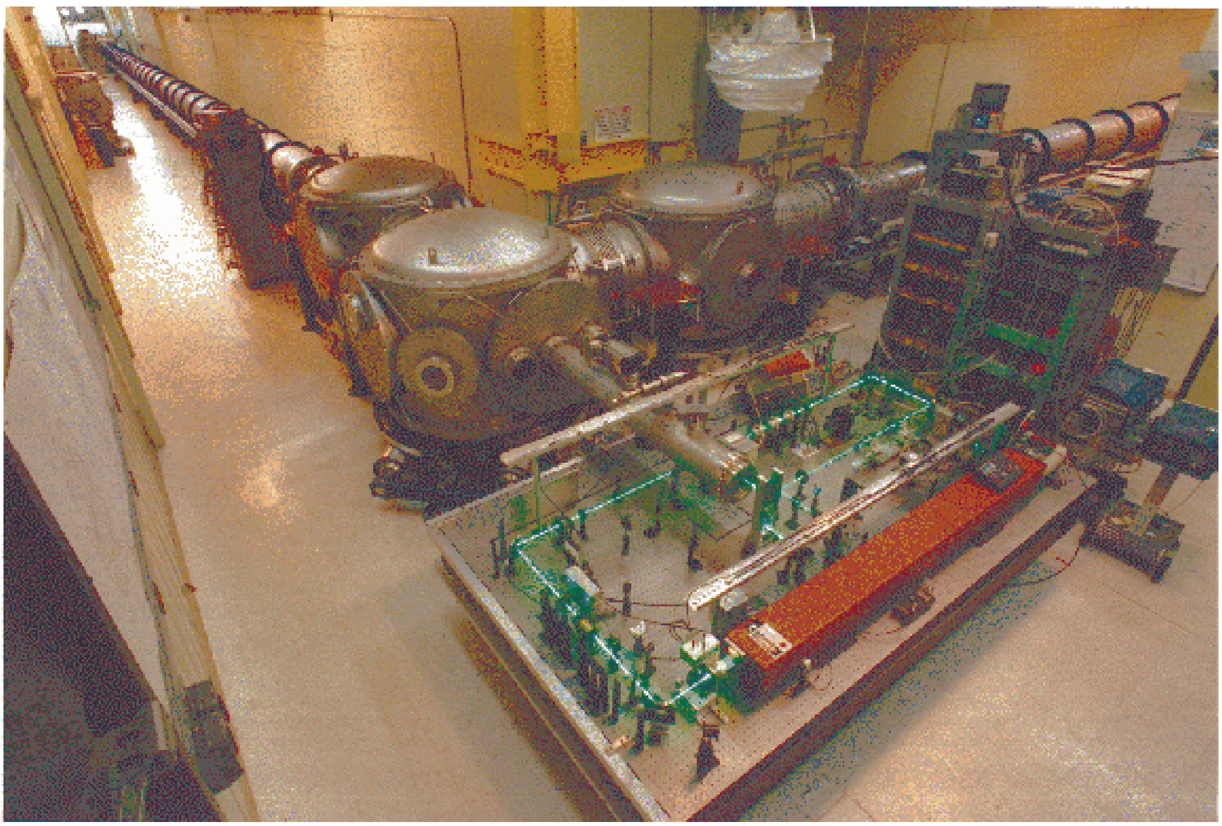
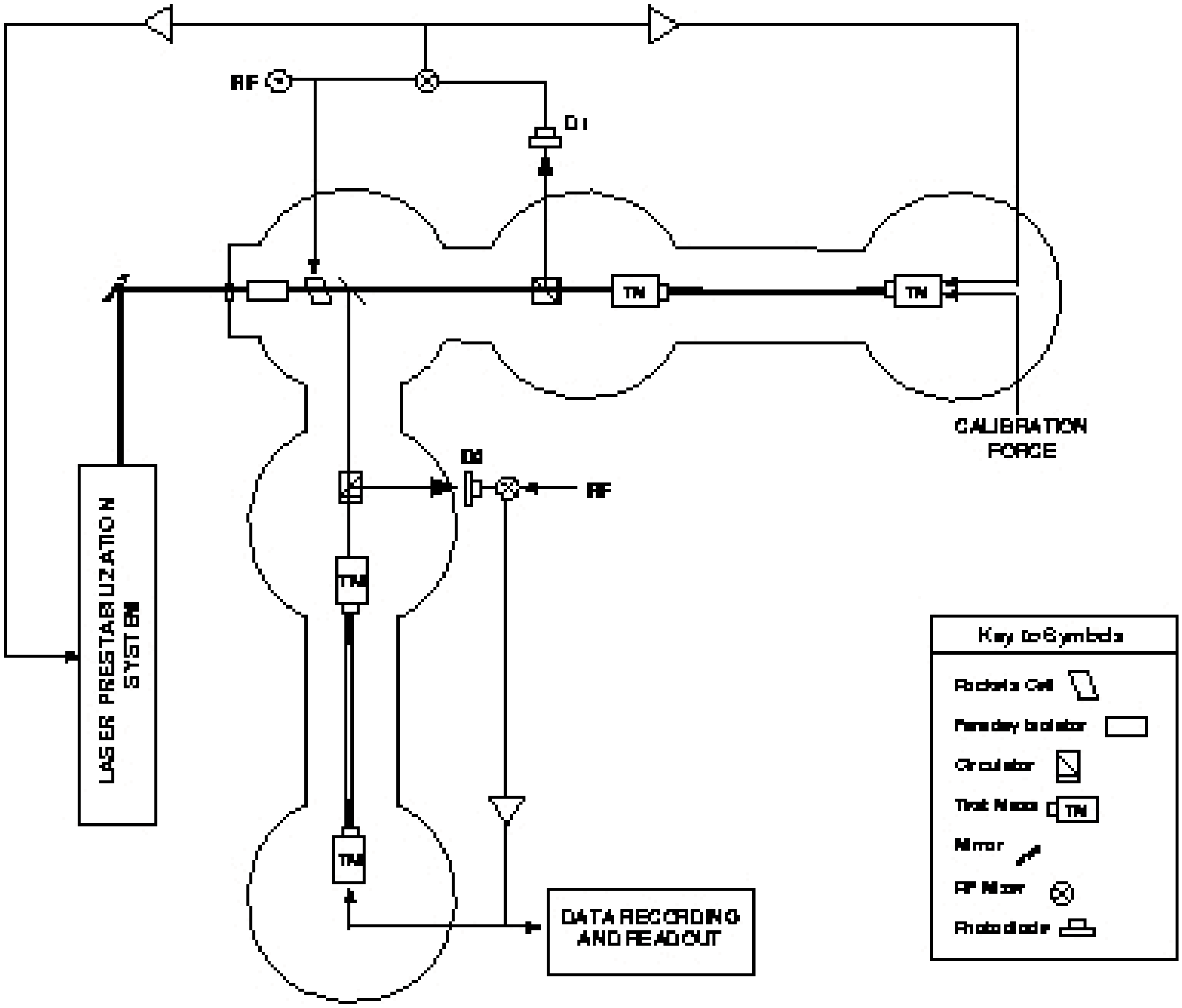
http://xxx.lanl.gov/abs/gr-qc/9903108

Allen, Blackburn,Brady, J. Creighton, T. Creighton, Droz,Gillespie, Hughes, Kawamura, Lyons, Mason, Owen, Raab, Regehr, Sathyaprakash, Savage, Whitcomb, Wiseman

The LIGO 40-meter prototype in November 1994



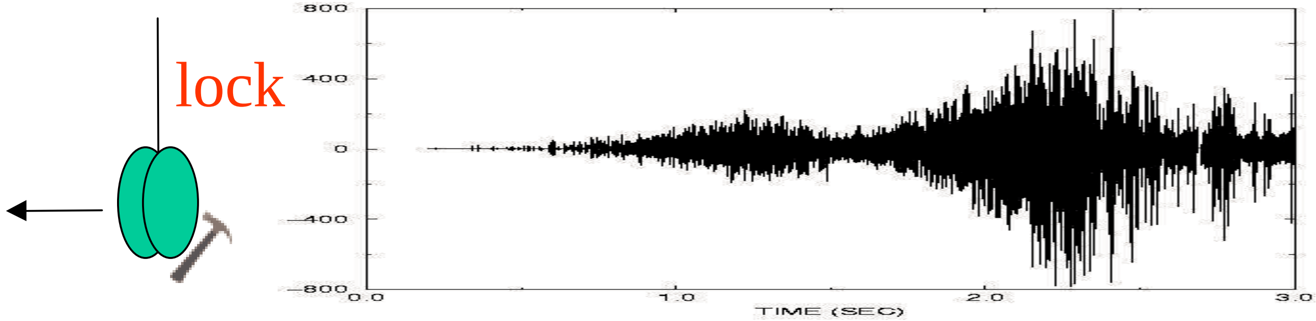
Optical Topology of 40-meter prototype in November 1994

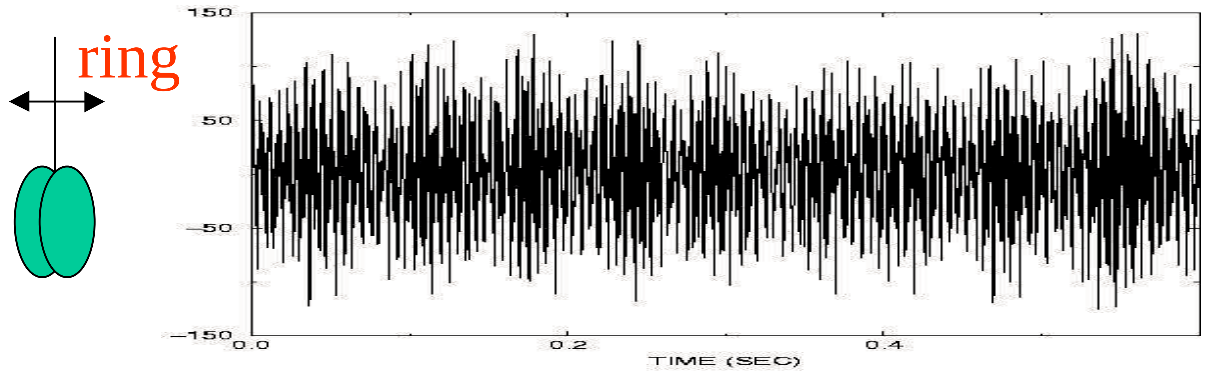


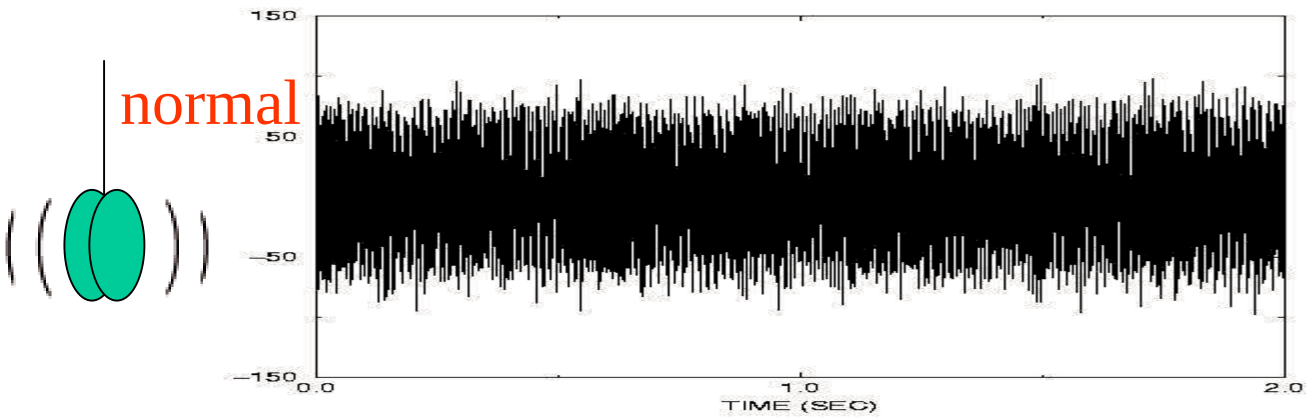
Similar to full scale LIGO except:

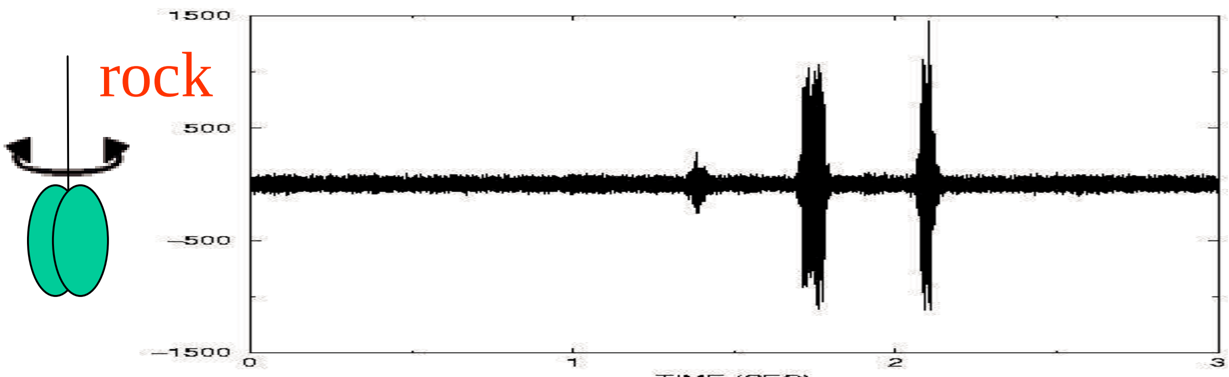
- No power recycling
- Recombination is electronic, not optical.

Interferometric Data is **ugly**!

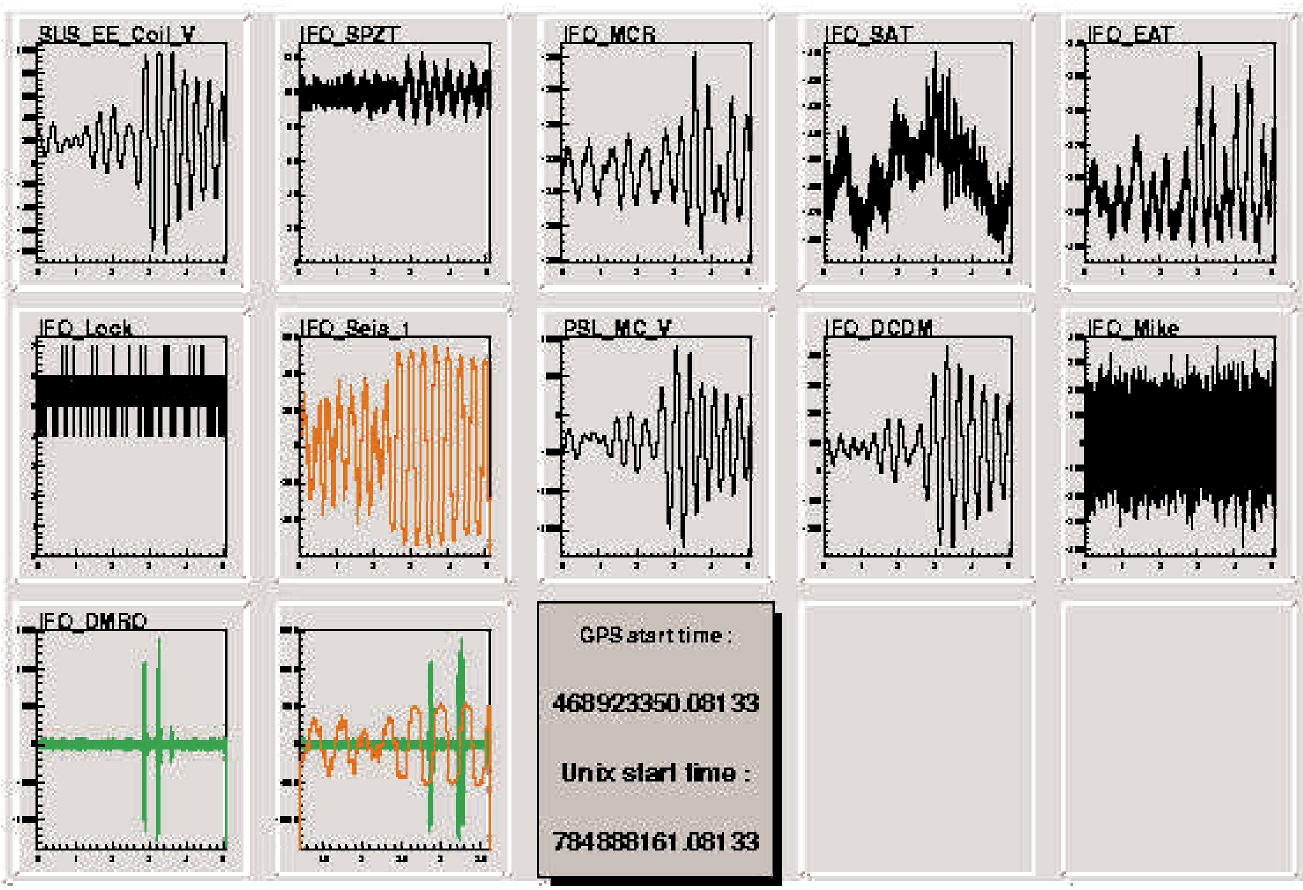






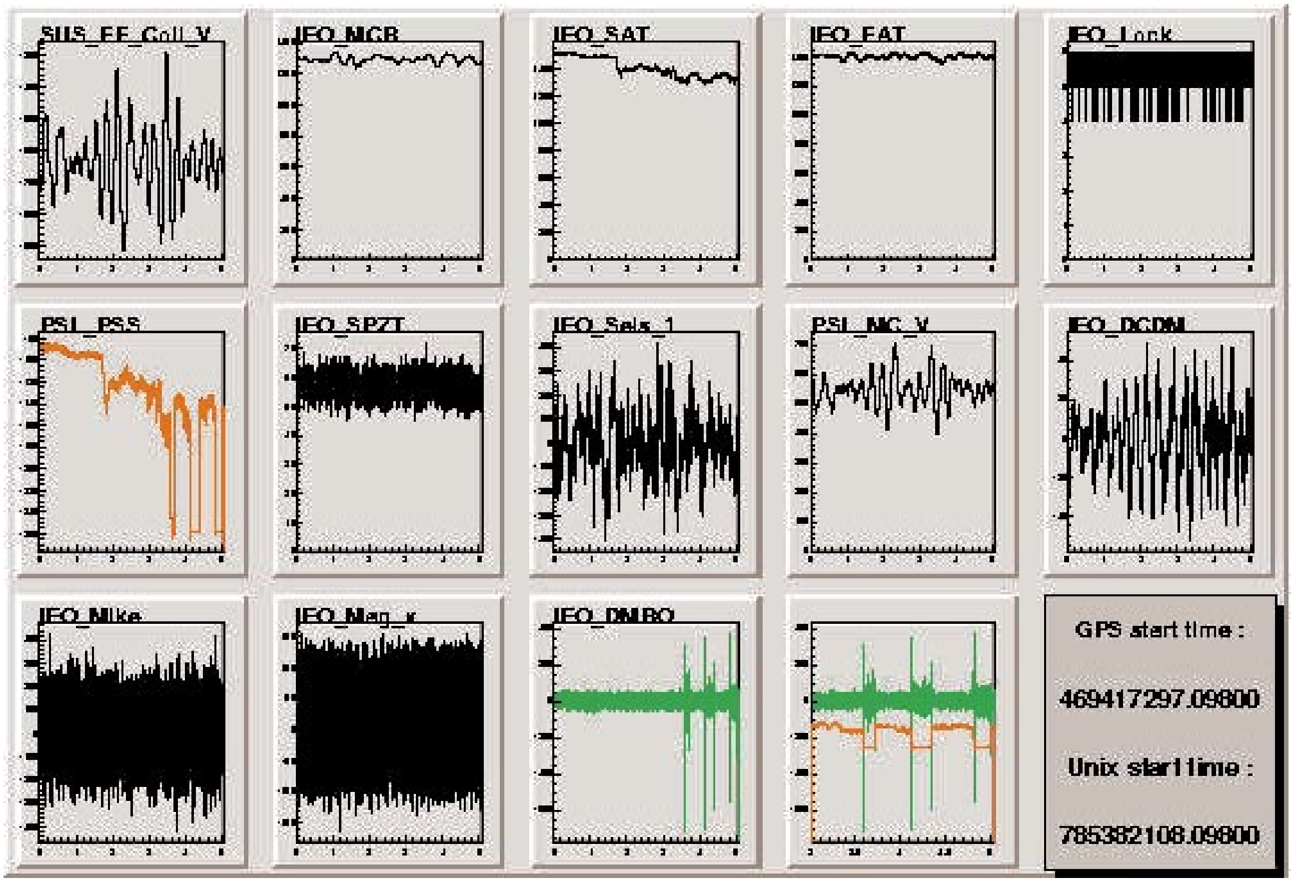


Data is multichannel



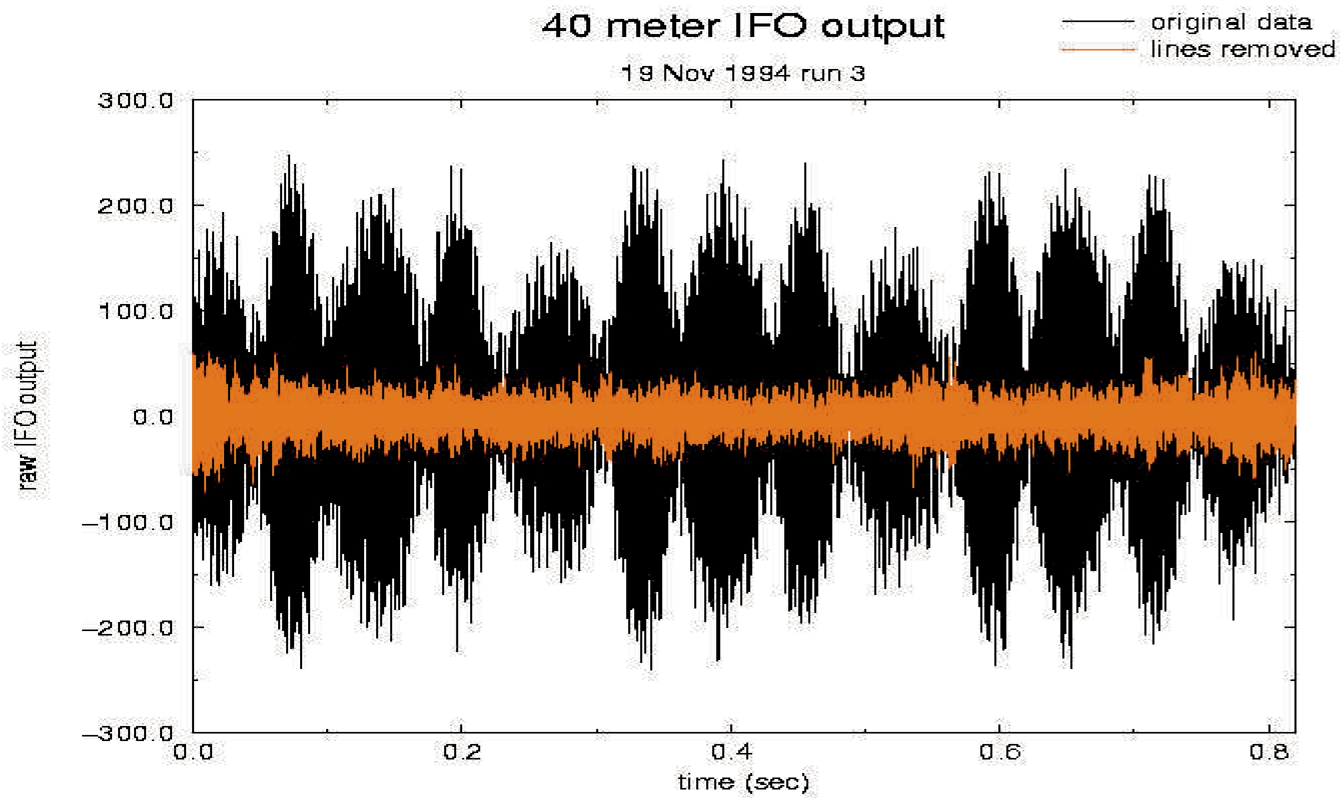
Shown: earthquake rocking the mode cleaner suspension at 2.7 Hz. This causes alignment errors giving rise to spurious optical modes.

Data is multichannel



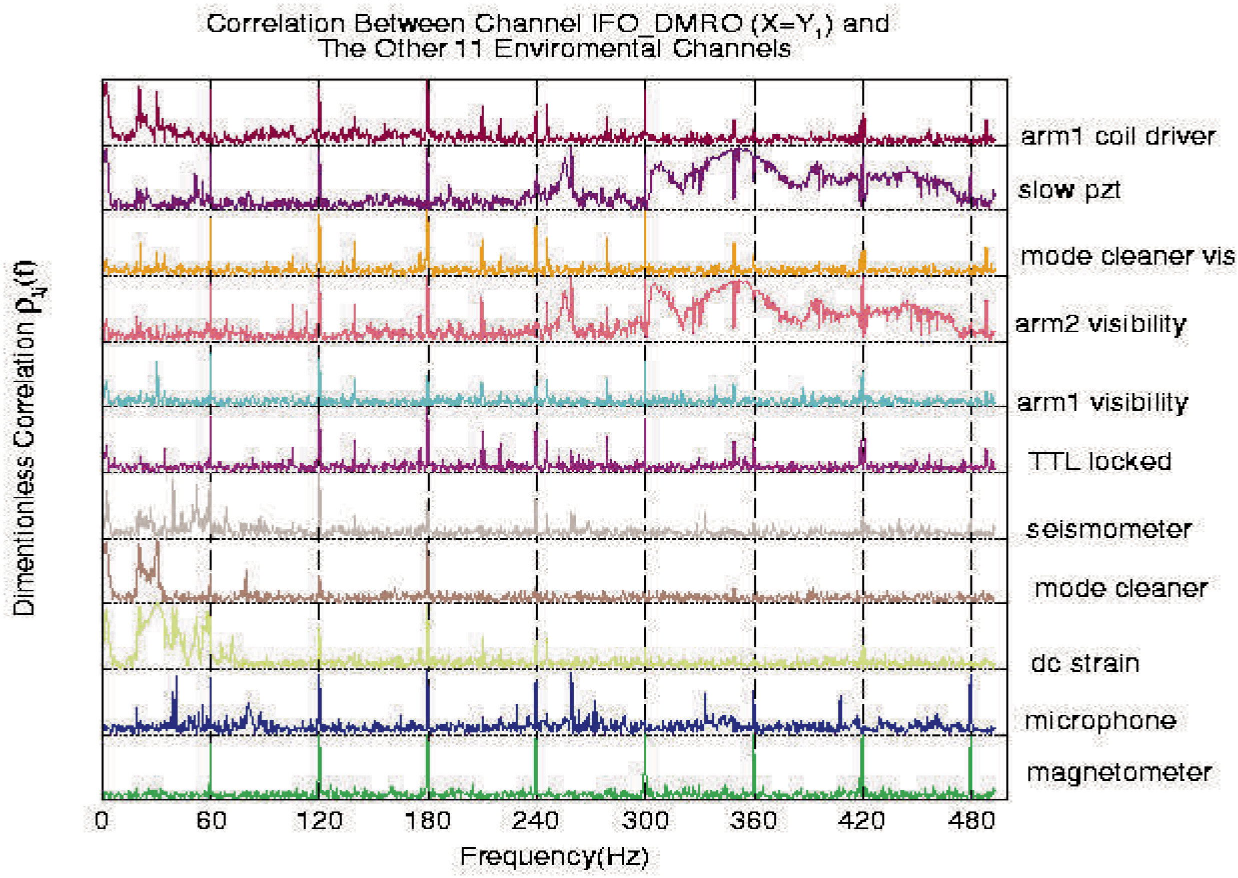
Shown: power level fluctuations in the laser (possibly due to saturation in a stabilization feedback loop).

Major Challenge: "clean up" data stream

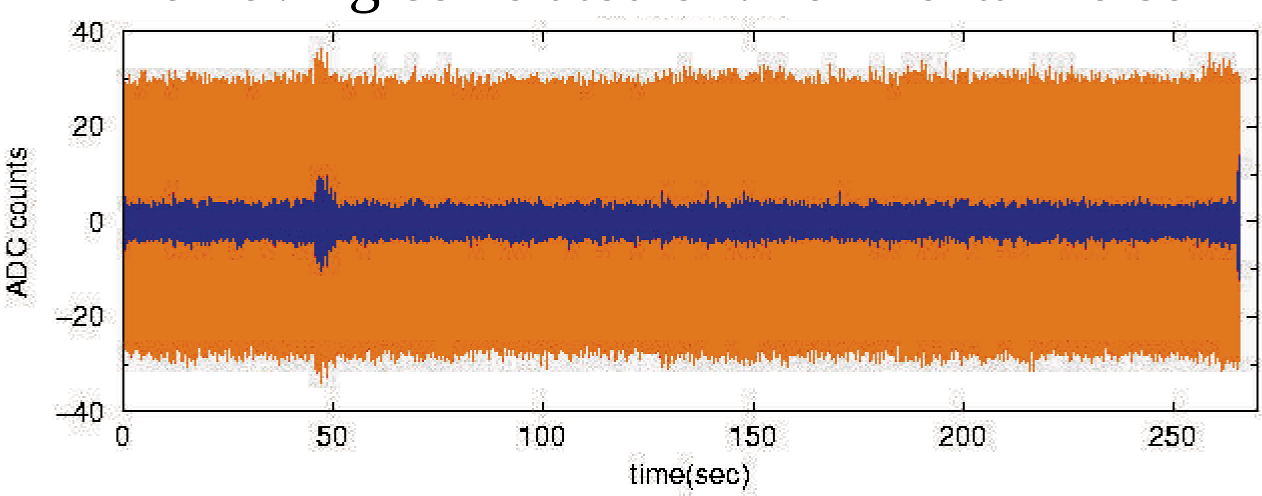


This shows the effect of removing sinusoidal artifacts using multi-taper methods

Major Challenge: "clean up" data stream

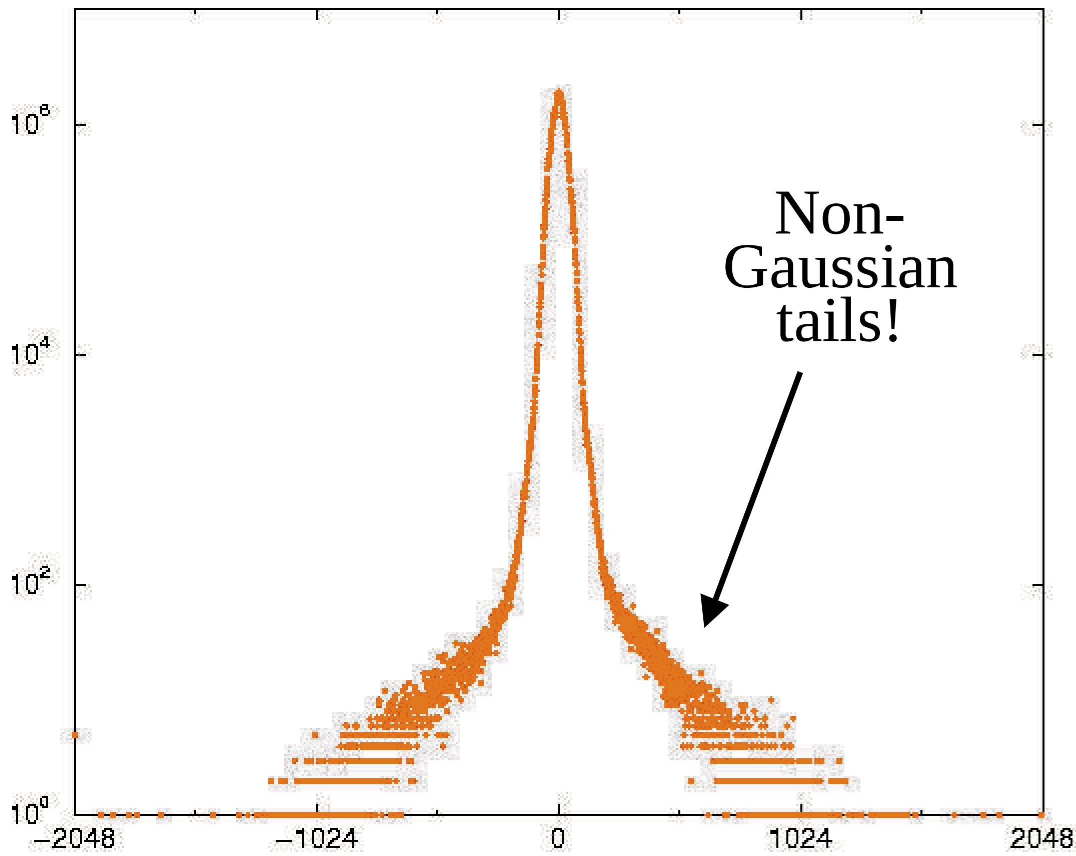


Interferometer output, before and after removing correlated environmental noise



Data non-Gaussian

Histogram of Raw Data

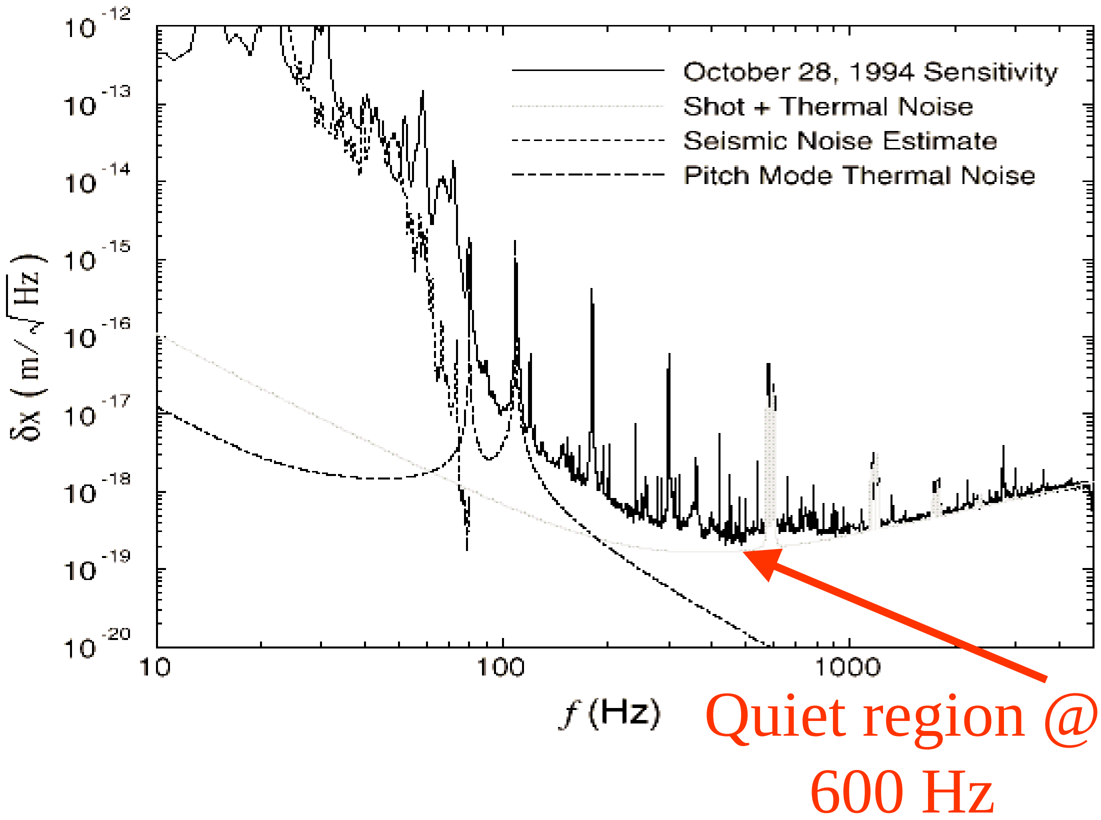


ADC value (12 bit, signed)

Key Question:

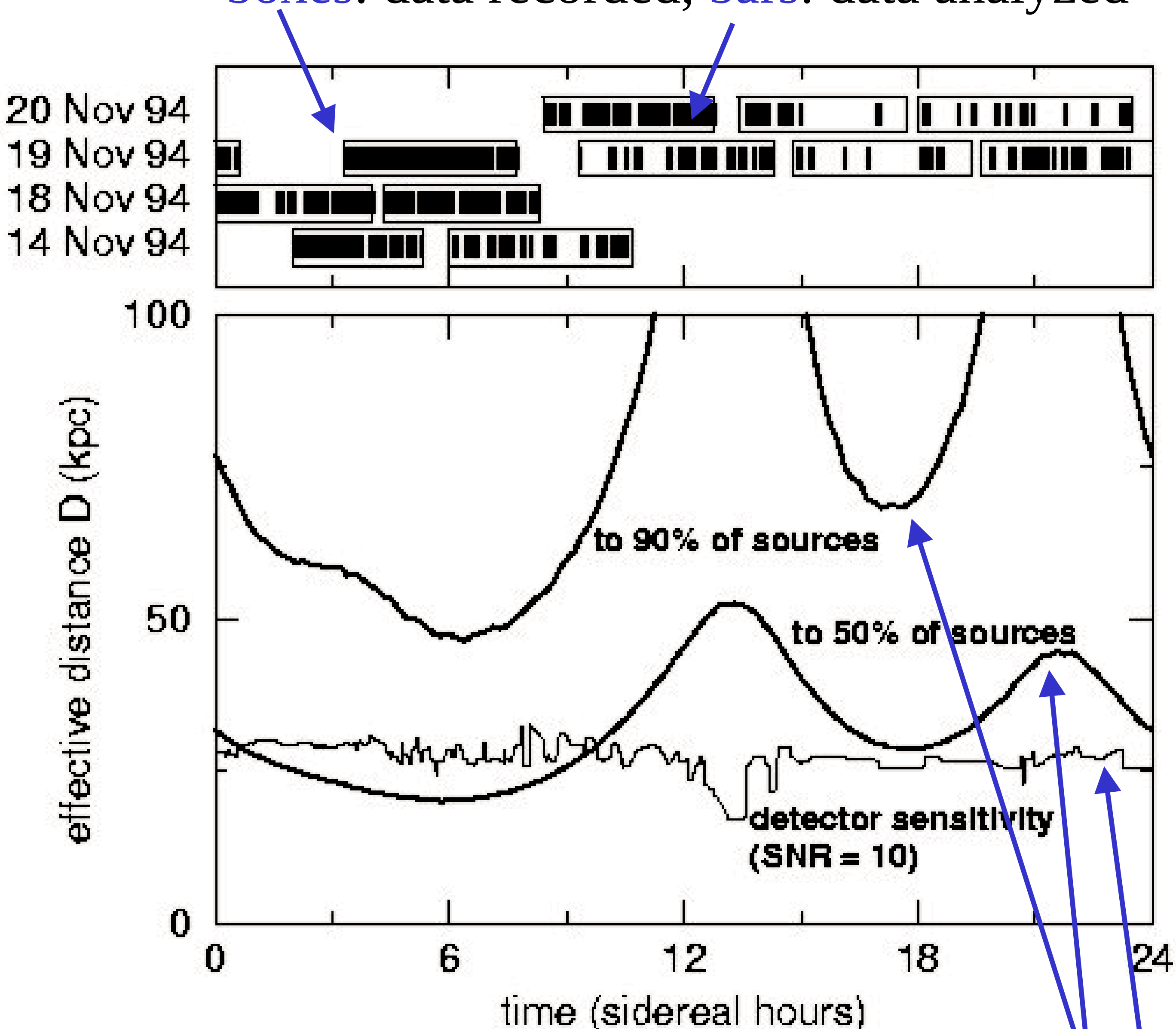
Can one do sensible analysis in the presence of this poorly-understood corruption of the data?

Proof of principle: Set upper limit on the rate of galactic NS inspiral using November 1994 40-meter data.



Data Taking Periods & Sensitivity

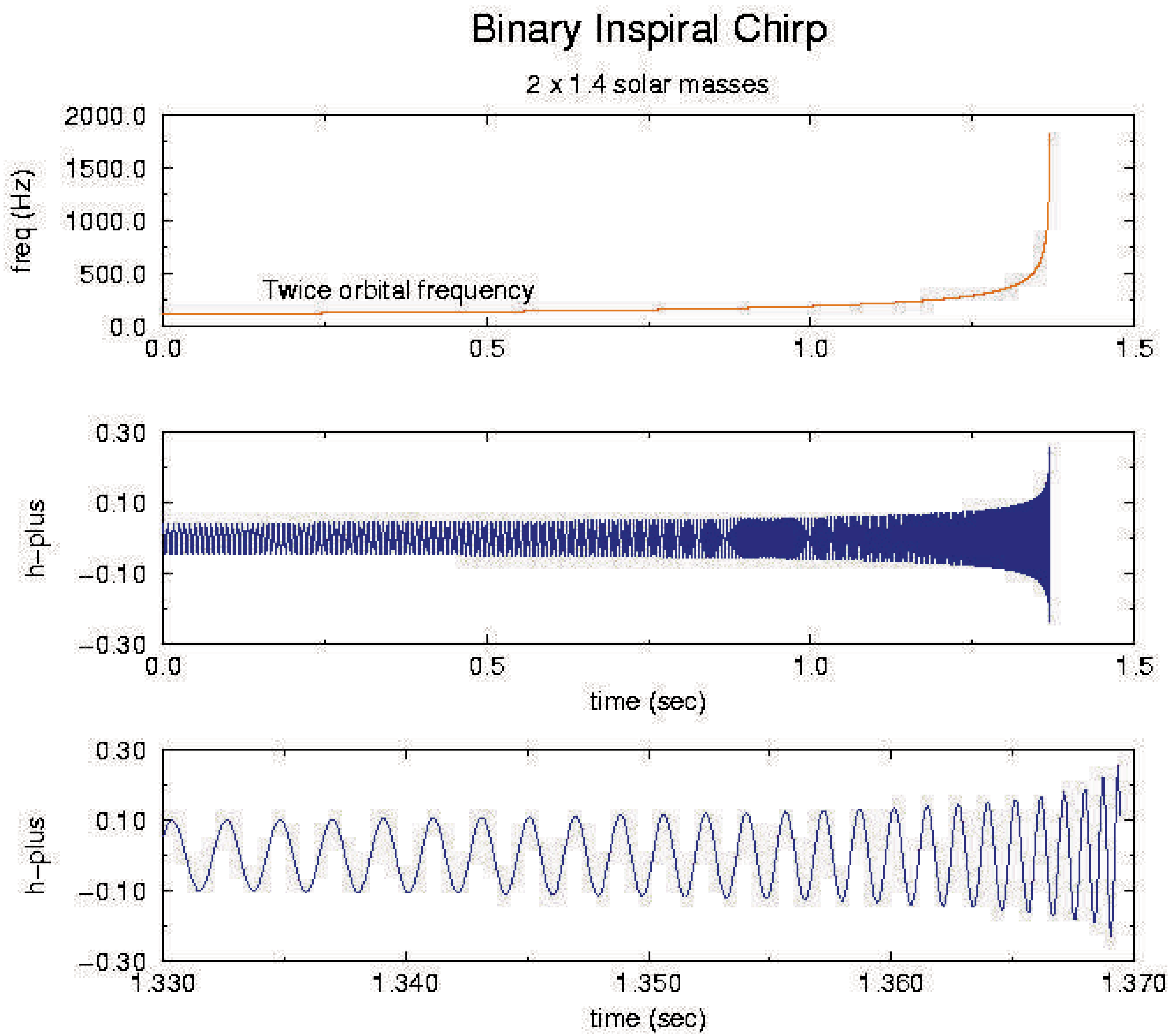
boxes: data recorded, bars: data analyzed



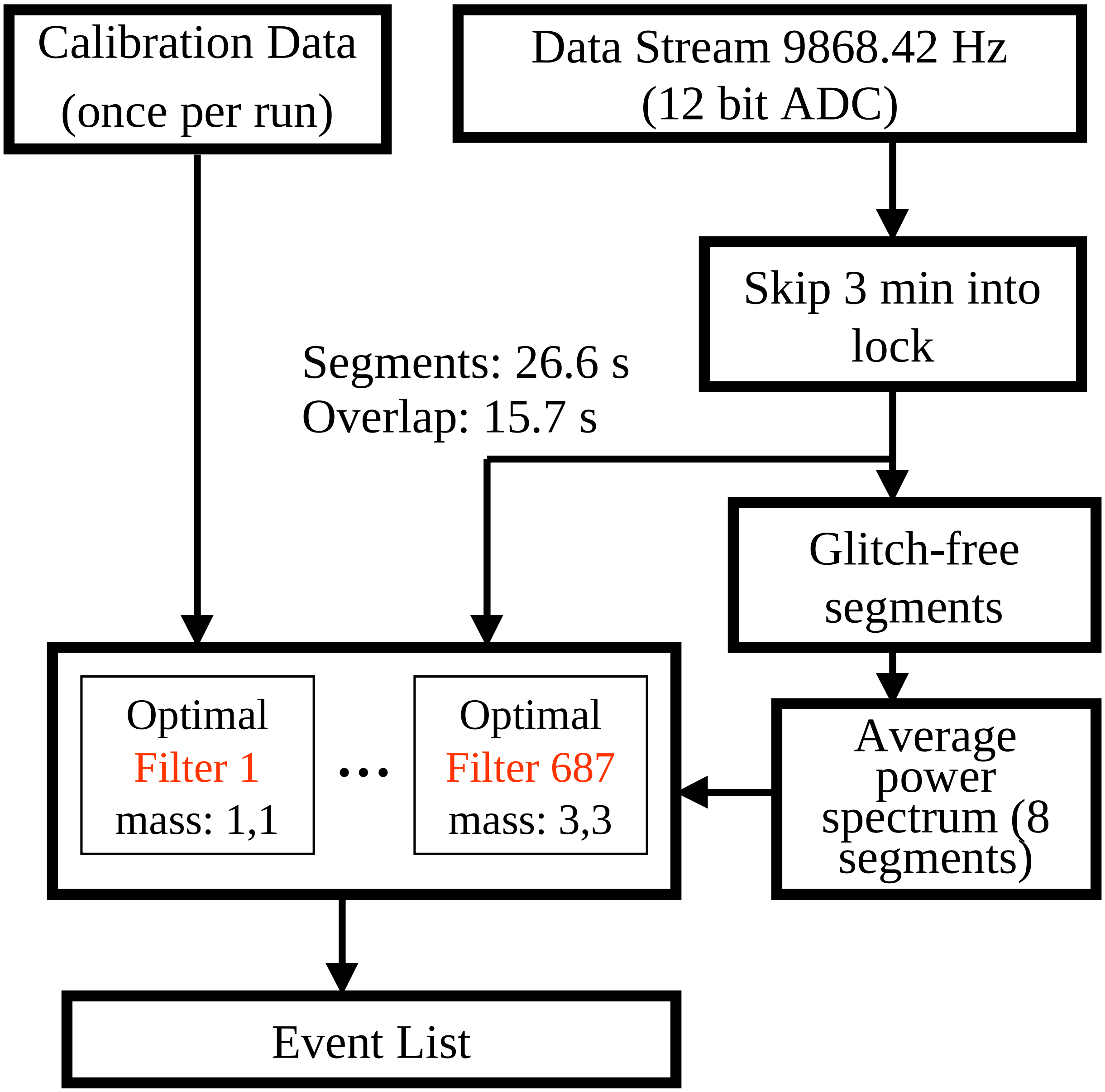
effective distance to 50% or 90% of sources

effective distance for Signal-to-Noise ratio = 10

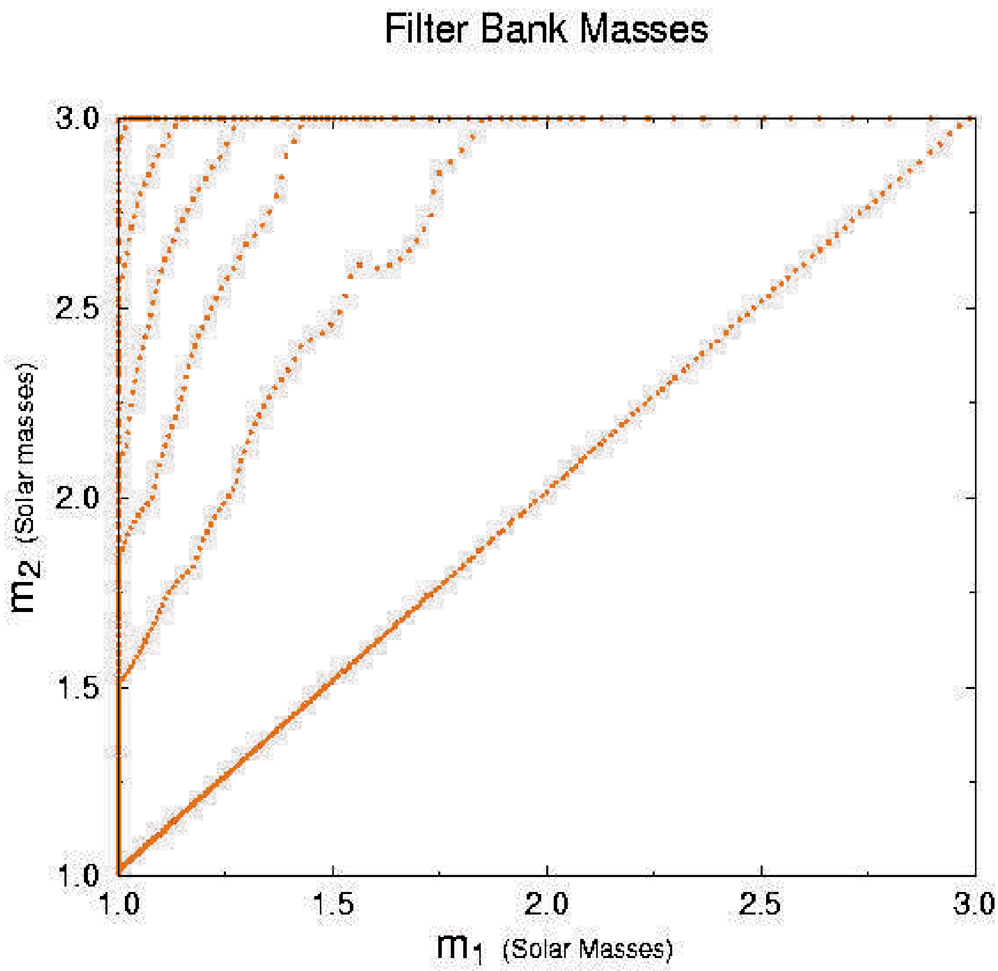
Typical Inspiral Chirp Signal



Filtering Method
(optimal/matched/Wiener)



Gridding of Filters



- 687 different mass pairs (1 to 3 solar masses)
- "Evenly" spaced in "overlap" space
- No more than 2% loss of SNR due to parameter mismatch

“Beowulf” Filtering Engine
(U. Wisconsin - Milwaukee)

48 x 300 MHz DEC α (linux)

29 Gflops peak

6 Gflops real (fft bound)

Filtering 25 hours of data takes 32 hours

Cost: $65K

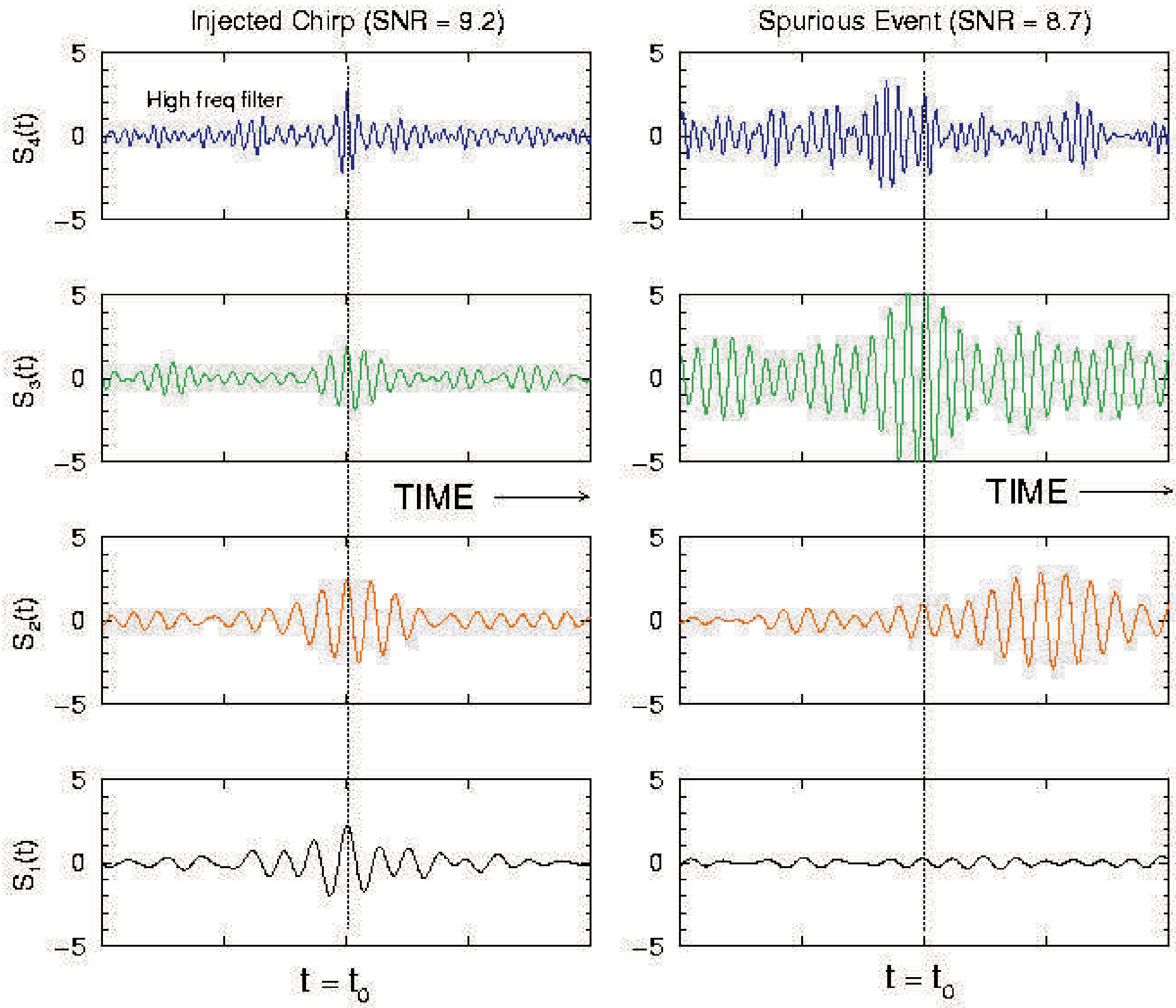
Time/Frequency Discriminator (χ^2 test)

Spurious interferometer noise rings off filters. To discriminate these large filter outputs from inspiral signals:

- Break frequency band into p=20 subintervals
- Subintervals chosen to make equal SNR contributions
- χ^2 = sum of squares of deviations from mean signal in band
- Statistic has 38 degrees of freedom

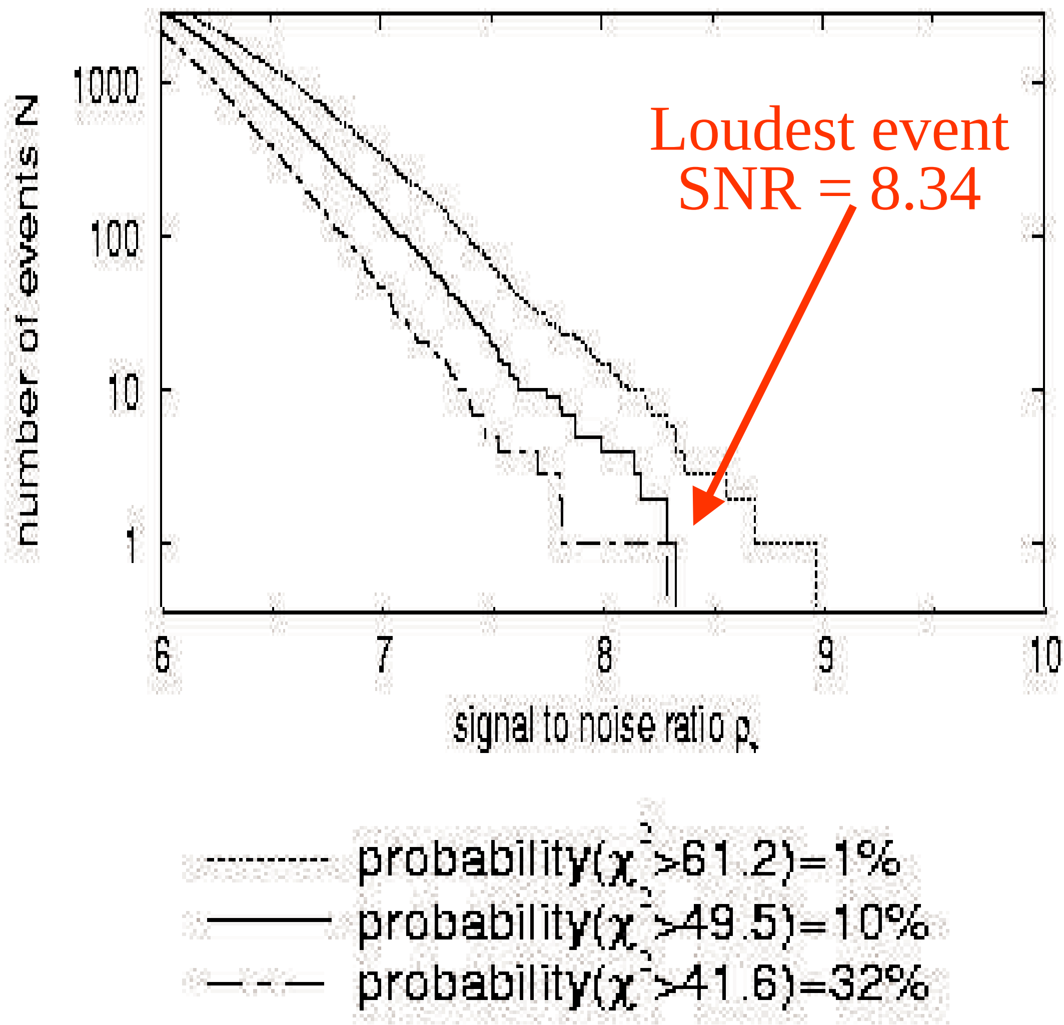
Time/Frequency Discriminator (χ^2 test)

How does it work? (p=4 band example)



$\chi^2 = 1.26$ $\chi^2 = 68.4$

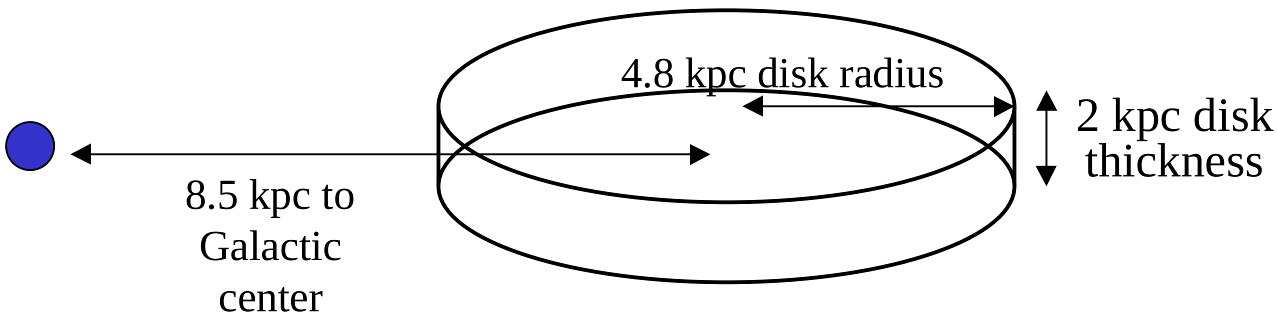
Results of Filtering



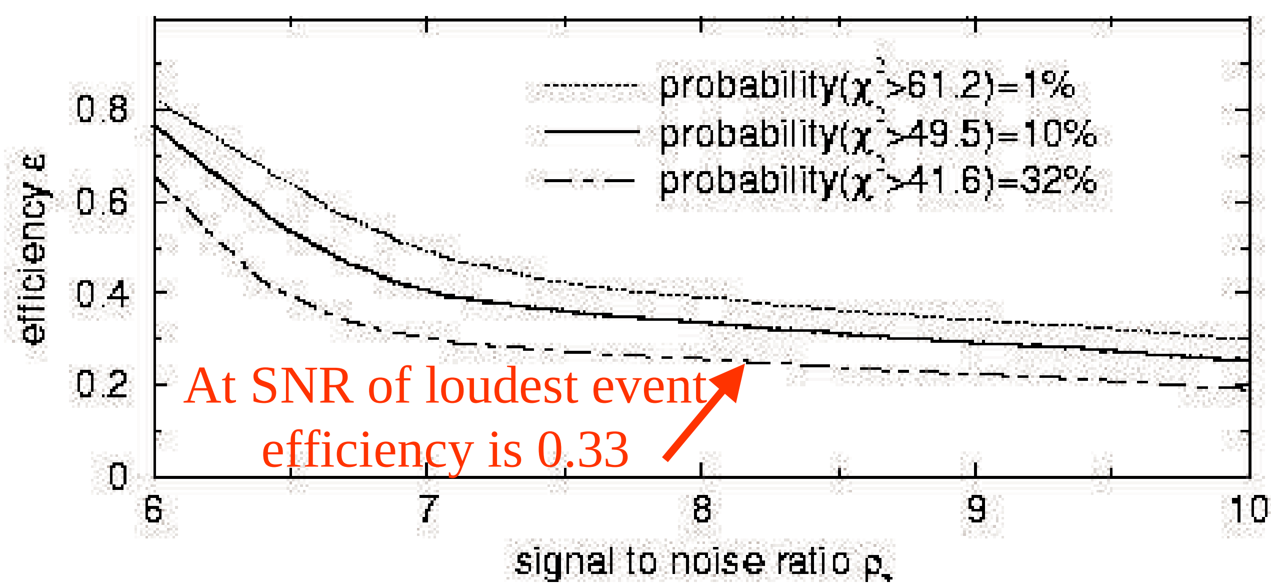
Upper limit on event rate can be determined from SNR of loudest event

Detection Efficiency

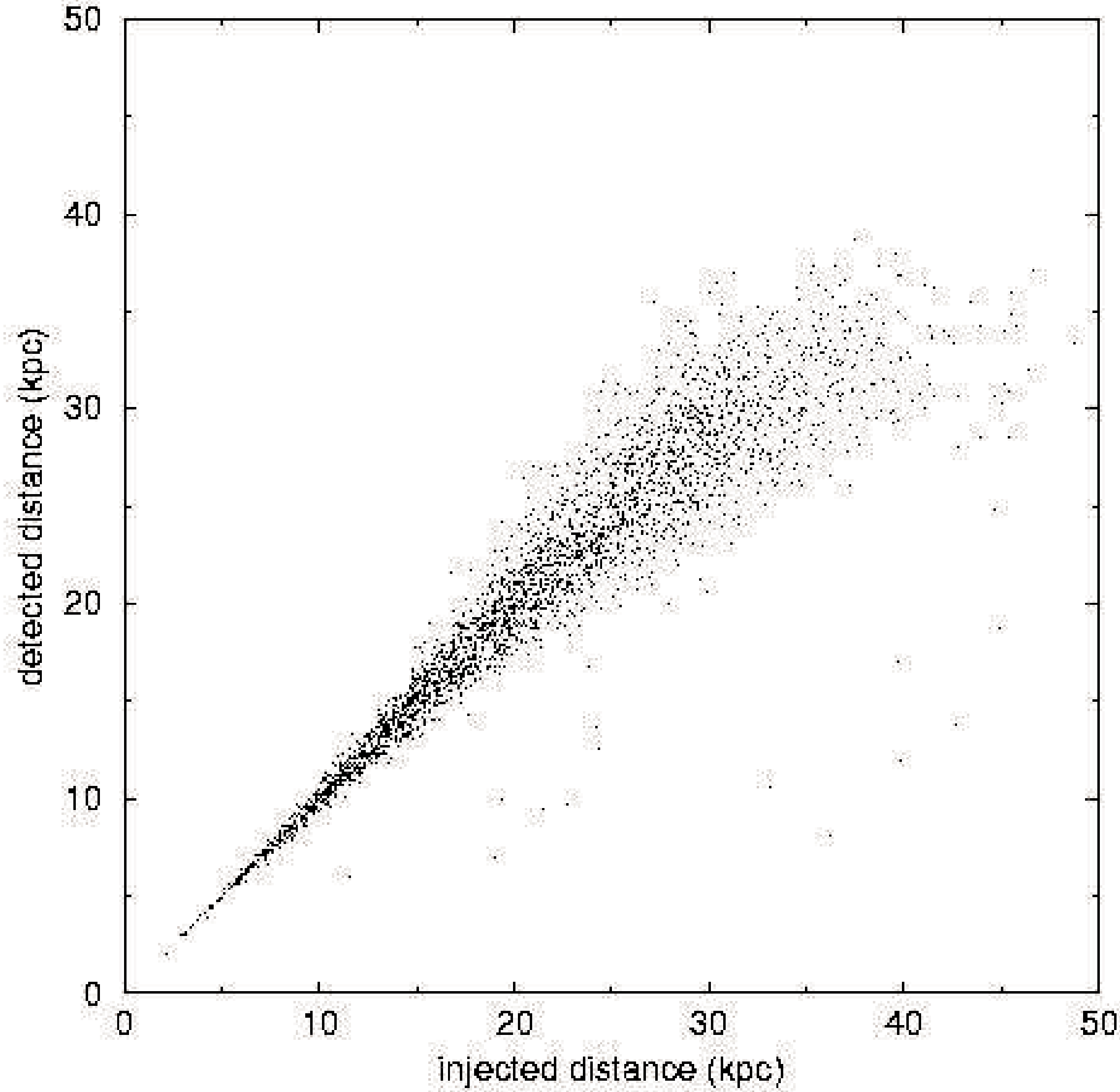
Step 1: simulate galactic distribution of binary inspirals sources:



Step 2: inject thousands of simulated signals into real output from instrument. What fraction are detected above SNR of loudest event?



Simulating Inspiral Events provides End-to-End test of analysis & simulation code



Several thousand simulated events are correctly detected. Errors in distance measure is consistent with expected SNR fluctuations.

90% Confidence Limit on Rate of Galactic Inspiral

Limit on Rate:

$$R < \frac{3.89}{\varepsilon\, T} = 0.5/\text{hour}$$

Numerator: determined by confidence (90%)
$\varepsilon = 0.33$ = detection efficiency at loudest event
$T = 25.0$ hours = total length of analyzed data

An ideal detector would have $\varepsilon = 1.0$ so the limit would be 0.16/hour.

More than half of the difference arises because detector antenna pattern makes effective distance to Galactic sources too large to detect

What Next?

Next step: simulated coincidence analysis with 40-m data

• Construct data base of events & instrumental monitors

• Introduce artificial time/space shift to half of the data stream, to simulate simultaneous operation of two sites

• Construct lists of correlated events

• Carry out further analysis of raw data around interesting time windows

• Use real not simulated data:

- don’t know how to simulate glitches
- hardest part is handling non-stationary and non-Gaussian noise

• Build methods into LDAS framework