Search for Gravitational Wave Repeaters

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Introduction 1

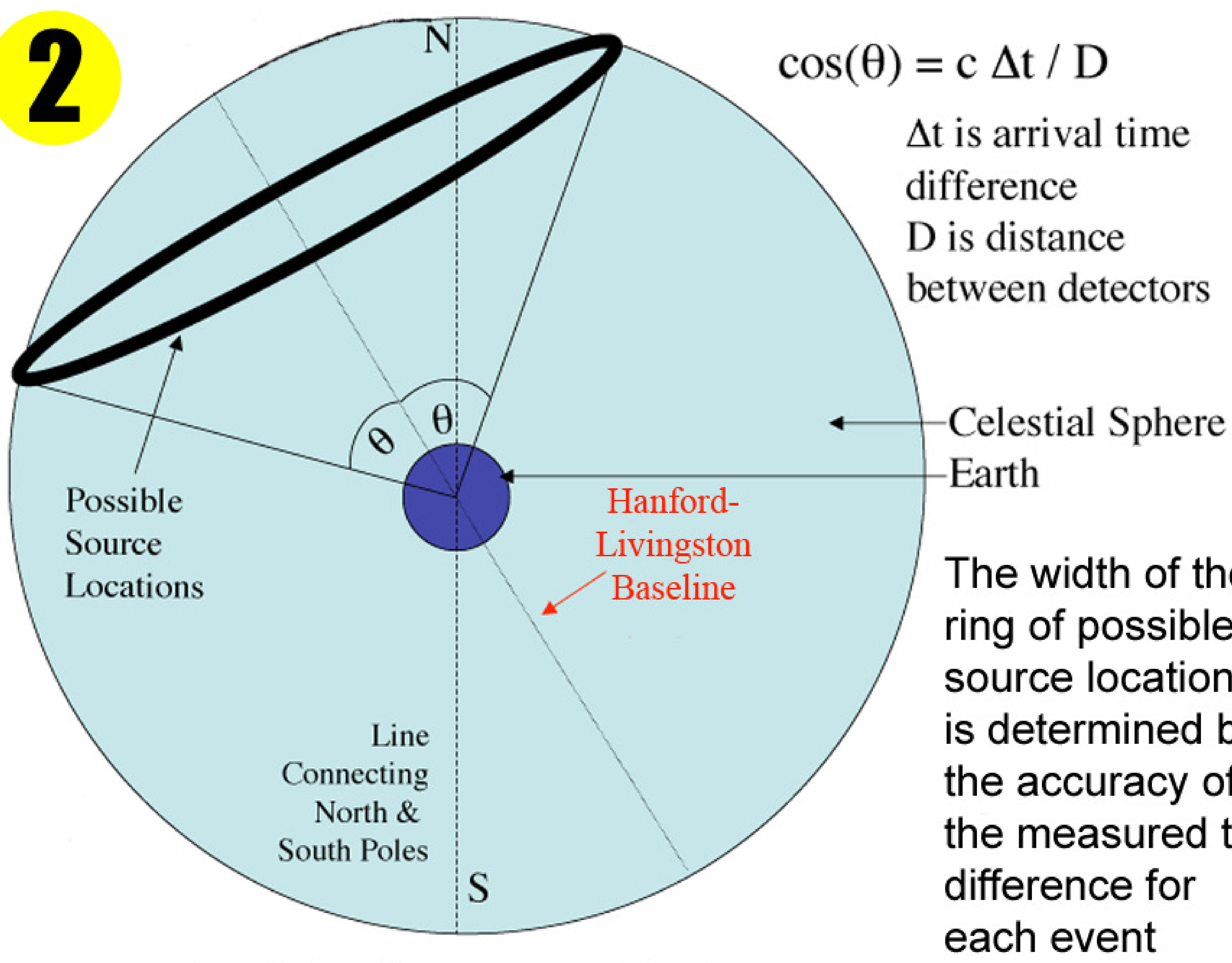
>Instead of searching for a "gold-plated" event we are looking for locations in the sky that may repeatedly emit gravitational wave bursts of detectable but not necessarily exceptional size.

>Any unknown, unvetoed glitches occurring in the Hanford 4-km detector and the Livingston 4-km detector at about the same time are considered as a possible GW candidate.

>Glitches are found from some other analysis like Q-Pipeline (Chatterji et al 2004 *CQG.* **21** S1809) and used to provide trigger times.

>At those times we rank-correlate the Hanford and Livingston data streams to find the time difference of the candidate event in order to establish directionality.

Triangulating 2



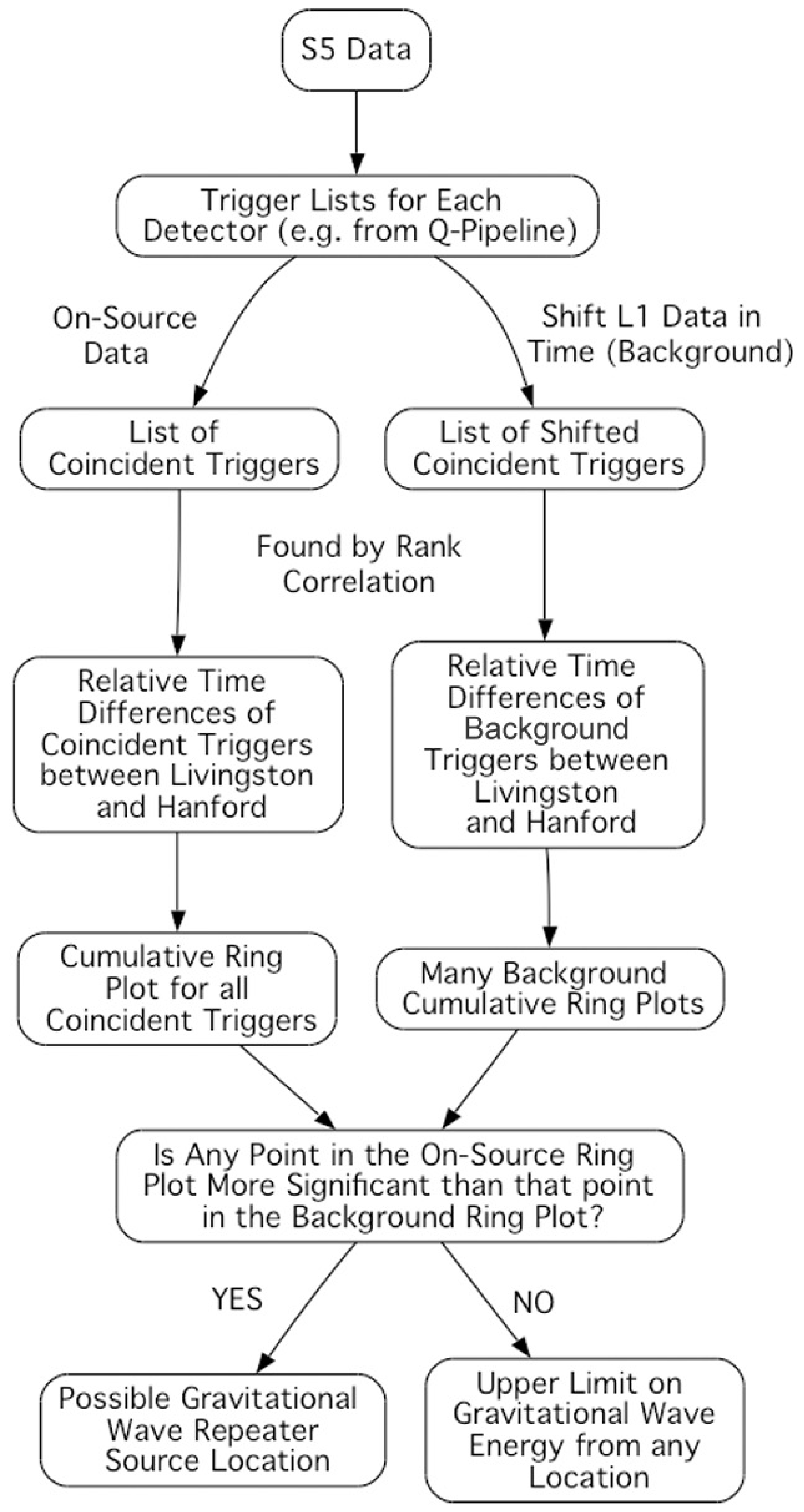
$\cos(\theta) = c\,\Delta t / D$

Δt is arrival time difference
D is distance between detectors

The width of the ring of possible source locations is determined by the accuracy of the measured time difference for each event

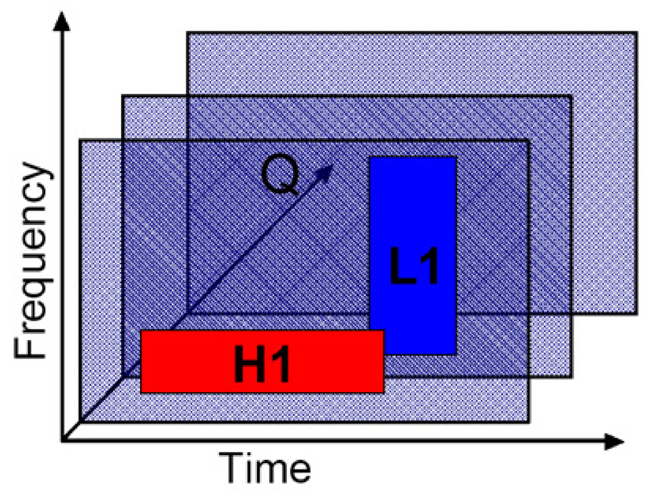
To plot a ring we need to know:

1.) Sidereal time of event (found from GPS of trigger)
2.) Time difference on event occurring at Hanford & Livingston (found from rank correlation)
3.) Accuracy on time difference (found from rank correlation)



Finding Coincident Triggers 3

1.) H1 & L1 triggers must be separated by less than 10 ms (the maximum time difference of a GW)
2.) H1 & L1 triggers must overlap in frequency
3.) H1 & L1 triggers must have similar Q (quality factor) values

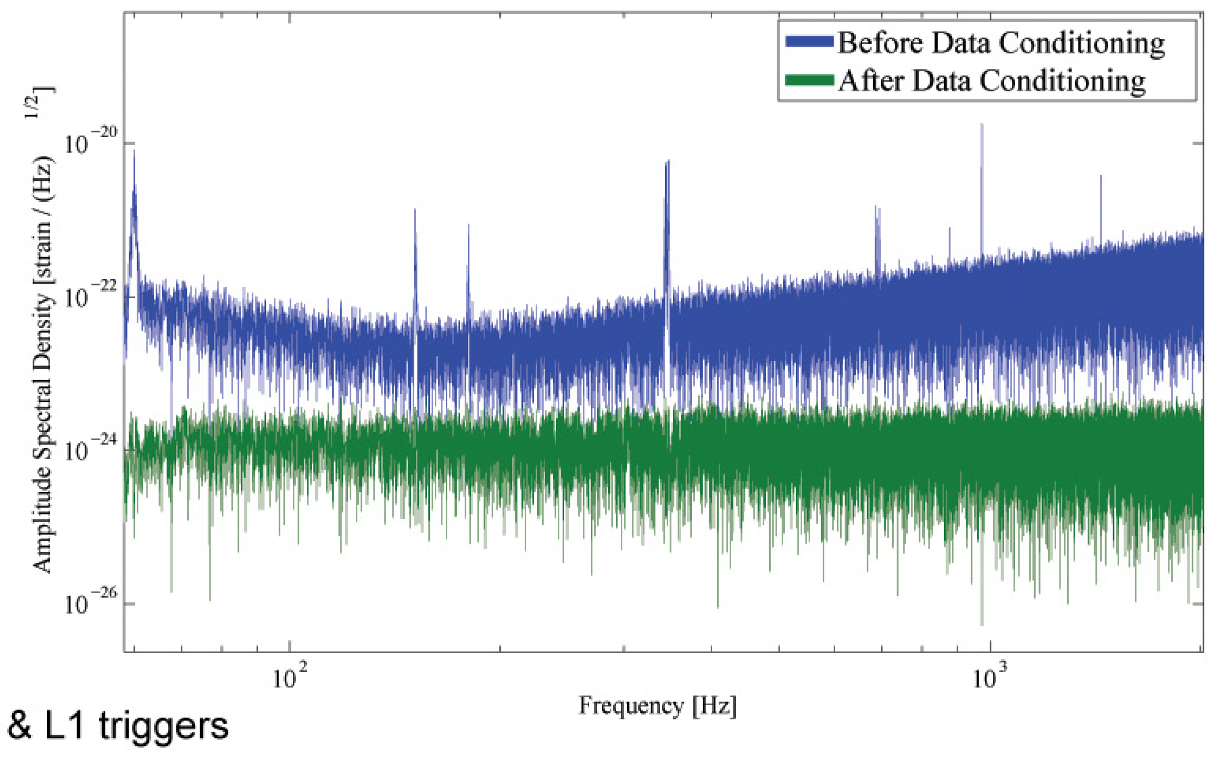


Determining the Time Difference of the Event at H1 & L1 4

Data Conditioning

>Notch Filter: 60 Hz line & harmonics, Calibration Lines, Violin Modes, etc.
>Linear Predictor to whiten data, otherwise largest line dominates rank-correlation
>Bandpass Data 50-2000 Hz (LIGO is insensitive outside this region)
>Trim beginning and end to remove any possible filtering artifacts
>Note: All filtering operations are done with zero phase filtering

Sample Amplitude Spectral Density Plot
Before and **After** Data Conditioning



Rank Correlation

>Measures the correlation between two data streams as a function of L1 being shifted in time
>Rank each value of H1 & L1 data points from 1 to N and compute:

$$r_s(j) = 1 - 6\frac{\sum_i^N (R(H_i) - R(L_{i+j}))^2}{N^3 - N}$$

>The integration length N is chosen to be the mean width of the H1 & L1 triggers

>Since the rank correlation is a non-parametric statistic, we don't need a priori knowledge of the distribution of H1 & L1 data to compute the significance. It is:

$$t(j) = |r_s(j)|\sqrt{\frac{N-2}{1-r_s(j)^2}}$$

>To prevent rejecting any possible gravitational wave signal we choose to select every peak above a predetermined threshold in the significance plot (i.e. one coincident event can correspond to multiple rings)
>To each selected peak we find:
>The time difference of the event occurring at H1 & L1
>The accuracy on the time difference value

Plotting Rings 5

>Represent the celestial sphere as a lattice.
>For each lattice point calculate the timing difference between H1 & L1 that a gravitational wave occuring at that location would produce:

$$\cos\delta_C \cos\delta_R \cos\alpha_C \cos\alpha_R + \cos\delta_C \cos\delta_R \sin\alpha_C \sin\alpha_R + \sin\delta_C \sin\delta_R = \frac{c\Delta t_{diff}}{D}$$

>δ_C,δ_R are the declinations of the line connecting the two detectors and the lattice point, respectively
>α_C, α_R are the respective right ascensions
>c is the speed of light
>D is the distance separating the detectors

> For each lattice point, estimate the likelihood of the potential gravitational wave originating at that location:

$$value(\alpha,\delta) = \frac{1}{\sigma\sqrt{2\pi}} e^{\frac{-(\Delta t_{diff}(\alpha,\delta)-\mu)^2}{2\sigma^2}}$$

>μ is the actual time difference between H1 & L1 for that event
>σ is the timing error for that event

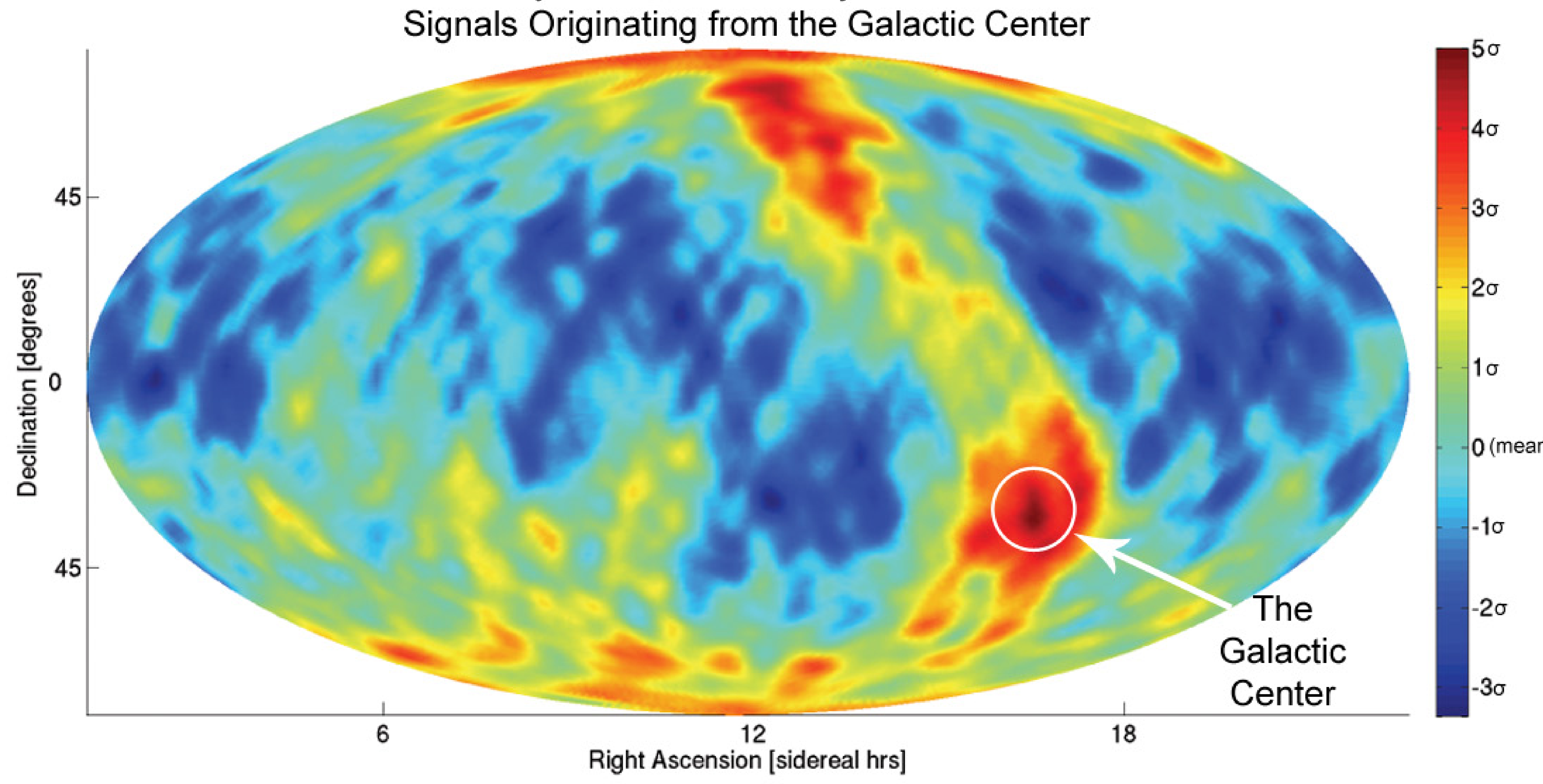
Evaluation of the Search Method 6

>To evaluate the performance of our algorithm we tested it on simulated LIGO data with 4 ms Gaussian waveform injections every six minutes. The data set was created for a directional LIGO-VIRGO analysis. The waveforms are injected into H1 & L1 so as to simulate a gravitational wave coming from the galactic center.

>There were 240 injected Gaussian signals with an average hrss of 1.27 x 10^{-22} [strain x $(Hz)^{-1/2}$]

>The search found 11,982 coincident triggers of which 2% were injected signals

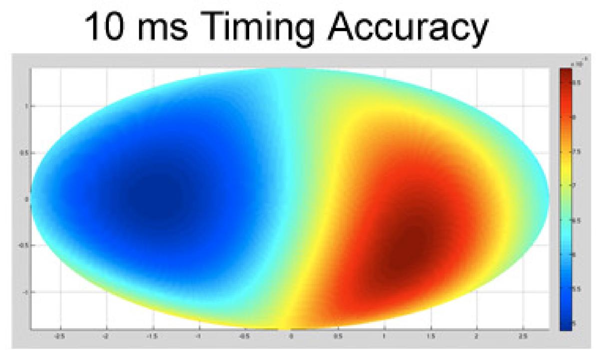
Recovery Performance of Injected Gaussian Signals Originating from the Galactic Center



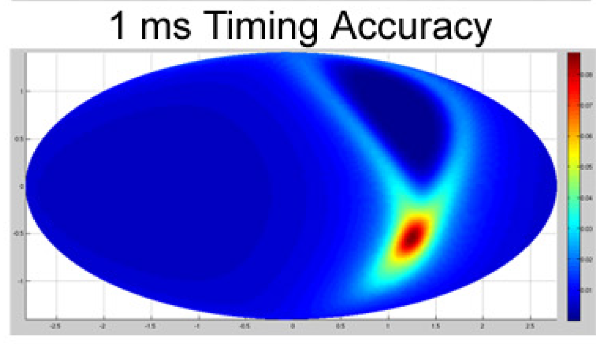
The stanandard deviation and mean were calculated from the middle 80% of locations on the sky map

>Below are all-sky maps of 240 injected signals produced by using the injection parameters of the LIGO-VIRGO study with various timing accuracies. A flawless search would produce these results.

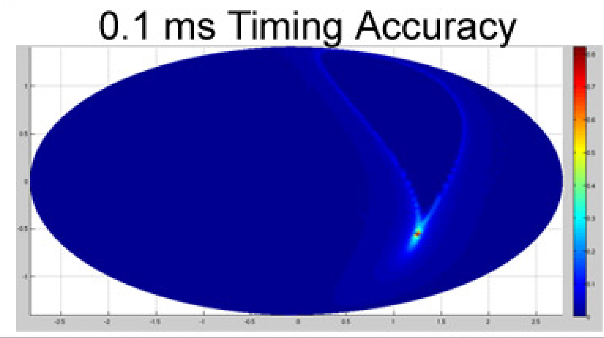
10 ms Timing Accuracy



1 ms Timing Accuracy



0.1 ms Timing Accuracy



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