THE PROBABILITY HORIZON FILTER AS A TOOL TO CONSTRAIN THE RATE DENSITIES OF TRANSIENT EVENTS

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Abstract

The brightness distribution of cosmological transient events is a powerful tool that can potentially constrain the luminosity function of the sources, their rate density evolution and local rate density. We show that by utilizing the temporal evolution of event brightness one can improve constraints on the local event rate density. To demonstrate this we have developed a filter that extracts the temporal evolution of brightness using simulated gravitational wave data assuming a population of binary black hole in-spirals. A joint fit to this data and the brightness distribution can constrain local rate densities to a higher precision than by using only the brightness distribution. The filter has potential applications to other classes of astrophysical transients such as gamma ray bursts and supernova.

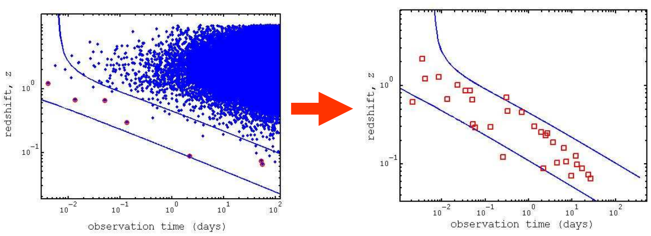
The concept of the Probability Event Horizon (PEH)

▪ When we switch on a detector, events from the peak of the probability distribution of our sources will dominate at early observation times. As time increases, rarer events at both high and low z will become more numerous.

▪ The temporal evolution of the most energetic events provide a background signal with a unique statistical signature. This signature is described by the Probability Event Horizon (PEH).

▪Using Poisson statistics and knowledge of the event rate a PEH curve is defined as the minimum z as a function of observation time for at least 1 event to occur at a confidence level defined by ε .

▪ A PEH filter simply extracts the most energetic events from a data stream as a function of observation time.



▪ *The simulated temporal evolution of a population of transient events for 4 months of observation time within z= 10. We assuming a local rate density of 0.03 Myr^{-1} Mpc^{-3}*

▪ *PEH data is shown by the red circles. The top and bottom curves represent PEH curves for ε values of 95% and 5%.*

▪ *The PEH data only constitutes a small subset of the total event distribution.*

▪*By splitting our data into subsets of equal observation time (in this example – 1 month), applying the PEH filter to each and recombining, you can increase the PEH data.*

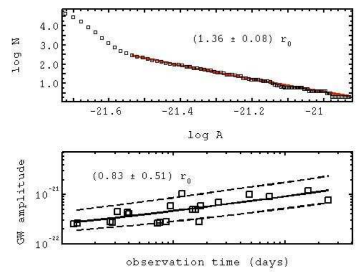
▪*For data streams of varying duration, Kolmogorov-Smirnov tests are used to verify that the data retains the statistical signature of the PEH.*

Application of the PEH filter to Binary Black Hole inspiral events with advanced LIGO

▪ Assuming Advanced LIGO sensitivities and an upper rate of Galactic Binary Black Hole (BBH) inspirals of 30 Myr^{-1}, we simulated GW data and applied a fitting procedure to PEH filtered data to estimate the local rate density r_0 .

▪ A comparison was made with a fit to the brightness distribution of events. For GW sources this is represented by log N-log A fit using the GW amplitude A.

▪ We considered two scenarios: one in which the detector ran at high efficiency, correctly resolving all injected events; secondly a suboptimum case in which the data contained both injected signals and false alarms.



▪ *Least squares fitting to the GW data for the suboptimum case.*

▪ *The top panel shows the log N- Log A fit – we dismiss events below log(-21.55) which are augmented by noise transients.*

▪*The lower panel shows the PEH fit.*

RESULTS

▪ We find the brightness distribution yields lower standard errors but is biased by false alarms.

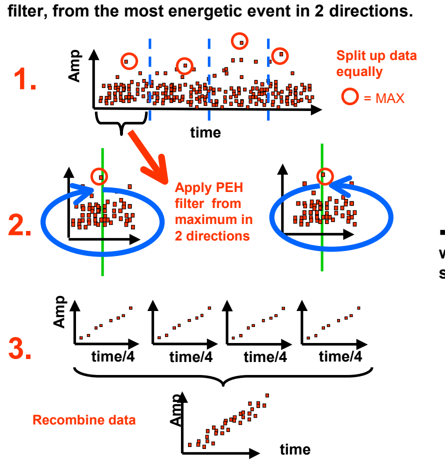
▪ The PEH method is less prone to errors from false alarms but has a lower resolution due to the smaller data set.

▪ Combining both estimates provides a self consistent test and increases the overall precision of the estimates by at least 1-2%

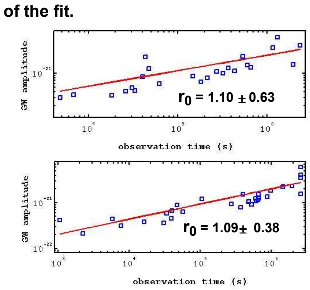
An improved PEH filter

We describe here the results of initial tests on techniques which can increase sample space of the PEH data and consequently, the accuracy and resolution of the fit.

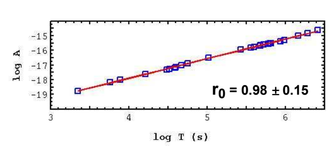
▪ Split up data as before, but this time apply the PEH filter, from the most energetic event in 2 directions.



▪ This technique increases the sample space and retains more of the data's temporal signature.



▪ The original PEH distribution is shown (top) along with the improved (bottom). The mean estimates are shown for 100 independent trials.



▪ Integrating the PEH data reduces the scatter, increasing the resolution and accuracy. The mean estimate for 100 trials is shown. For the case of GW amplitudes an integrated PEH curve has a gradient of 4/3 in a Euclidean geometry.

Summary

▪ The PEH filter utilizes the temporal and spatial distribution of a population of transient standard candles to constrain the rate density.

▪ Because the PEH distribution is composed of the most energetic events, the fits are only weakly affected by the inclusion of false alarms.

▪ The PEH fitting procedure has a lower resolution than the brightness distribution due to the reduced data from the PEH filter.

▪ A combination of fits, utilizing both the brightness distribution and PEH, can improve event rate estimates.

▪ An optimized PEH filter reduces the scatter, allows more data to be used and improves estimates.

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