Tracksearch: A Time Frequency Method for Gravitational Wave Data Analysis

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ASIS Session

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Tracksearch's Applicability

- Searching for unmodeled sources of gravitational radiation
- This particular search will be well suited to signals whose durations are the second to minute ranges.
  - gravitational waves that are strong enough to be visible on earth are due to bulk motions of matter and/or energy.
  - signals from bulk motion of matter could be broadband and in general die out quickly or rapidly settle down to a quasi equilibrium state emitting radiation with a fundamental frequency
  - long-lived system will be the result of coherent motions of matter, such as perturbations about the system equilibrium. The systems characteristic frequency is set by its physical parameters.

Algorithm Needs

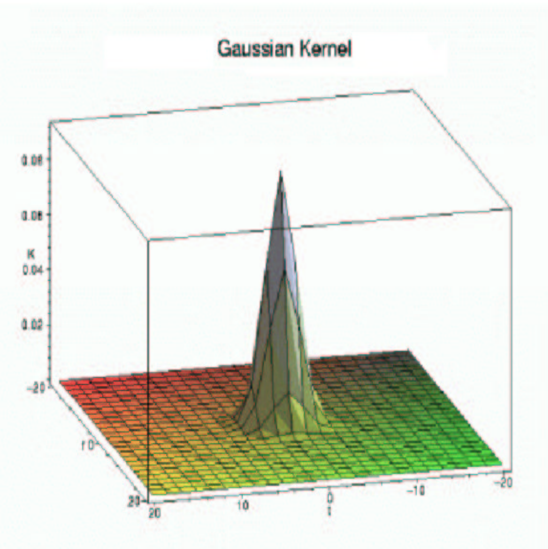
- Minimum algorithm search assumptions
  - every signal could be expressed as $h(t) = A(t)\sin(2\pi f(t)t)$
  - $f(t)$ is a slowly varying function of time $f(t) \approx f(t + \delta t)$
  - we also expect that the amplitude is slow varying function of time $A(t) \approx A(t + \delta t)$
  - δt is a lapse in time such that $\phi(t + \delta t) = \phi(t)$.
- We do not assume the following:
  - Signal amplitude evolution has predetermined form aside from its slow evolution
  - We don't expect any particular signal phase evolution
  - We do not have any preconceived physical model for our signals source

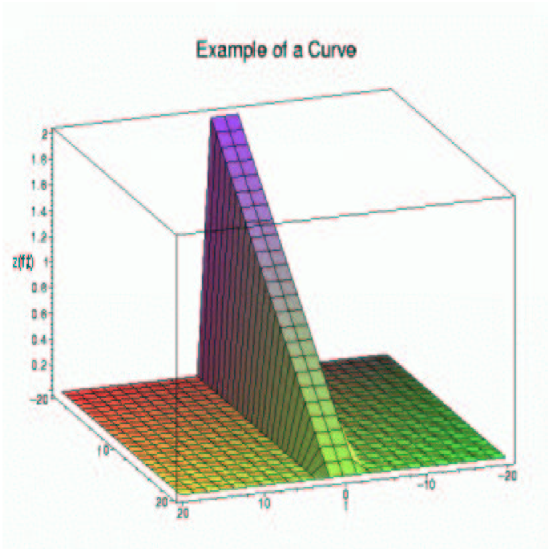
Time Frequency Maps

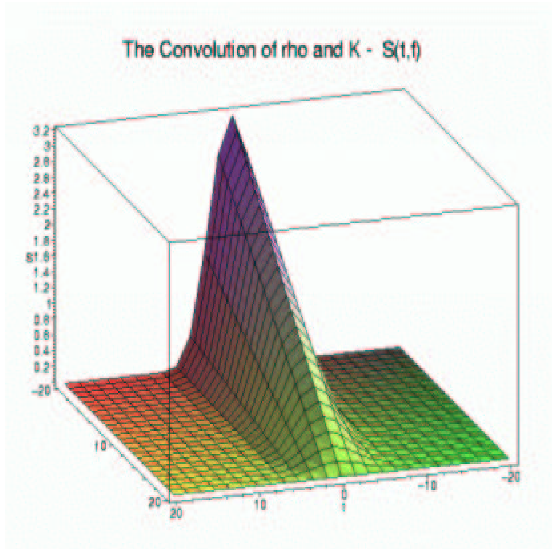
- There exist many choices for TF representation of data.
  - There are several transforms available, either bilinear or linear
  - Such as Wigner-Ville Distribution or the Spectrogram (SFT)
  - We have yet to decide on a “best” TF representation to use
- TF representation of detector noise has a characteristic TF topography, which is not a ridge.
- TF representation of signal is a simple TF topography of ridges
- We must use an algorithm that picks out ridges from assorted fluctuations in the plane of noise
- Each of the candidate ridges might possibly be a signal in the detector

TF Map Preparation

- The algorithm used to search for TF features was developed by a computer scientist named Carsten Steger
- Gravitation wave signal is a curve in a time frequency representation.
- Gaussian kernel convolution with signal provide a homogeneous ridge profile to search for.
- A ridge regardless of the particular shape, flat top or otherwise will now be a homogeneous feature







Finding Ridge Points

- The eigenvector corresponding to the smallest eigenvalue magnitude of our Hessian matrix could have been evaluated on a potential ridge point.

$$\begin{pmatrix} \frac{\delta^2}{\delta t^2} & \frac{\delta^2}{\delta t \delta f} \\ \frac{\delta^2}{\delta f \delta t} & \frac{\delta^2}{\delta f^2} \end{pmatrix} * H(t, f) \qquad (1)$$

- We demand that the second derivative exceed our lower second derivative threshold if this could be a ridge point

Finding Ridge Points Continued

- If the first is derivative parallel to the second derivative eigenvector has a zero derivative this pixel is at the top of a TF ridge.

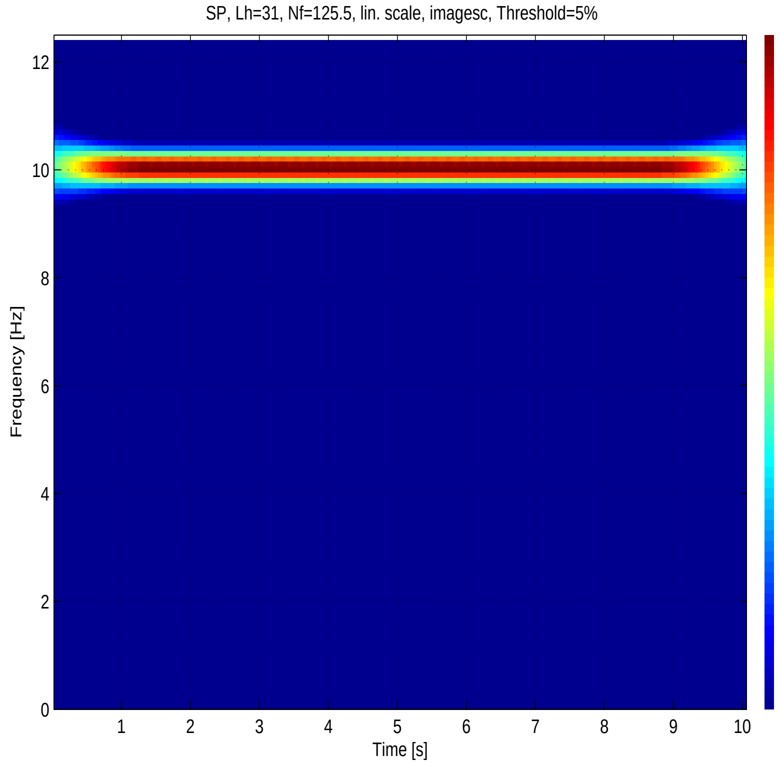
$$\left(r_t \frac{\delta}{\delta t} - r_f \frac{\delta}{\delta f} \right) H(t, f) = 0 \qquad (2)$$

- One also requires that potential ridge points neighbor each other in such a way as create a curve in the TF plane.
- The point may be the in on of two states:
  - Second derivative exceeds the higher threshold this is a definite ridge point
  - Pixel only exceeds the lower second derivative threshold and neighbors a ridge point it is a ridge point.
- Then groups of pixels who align perpendicular to the second derivative eigenvector can be called a ridge.

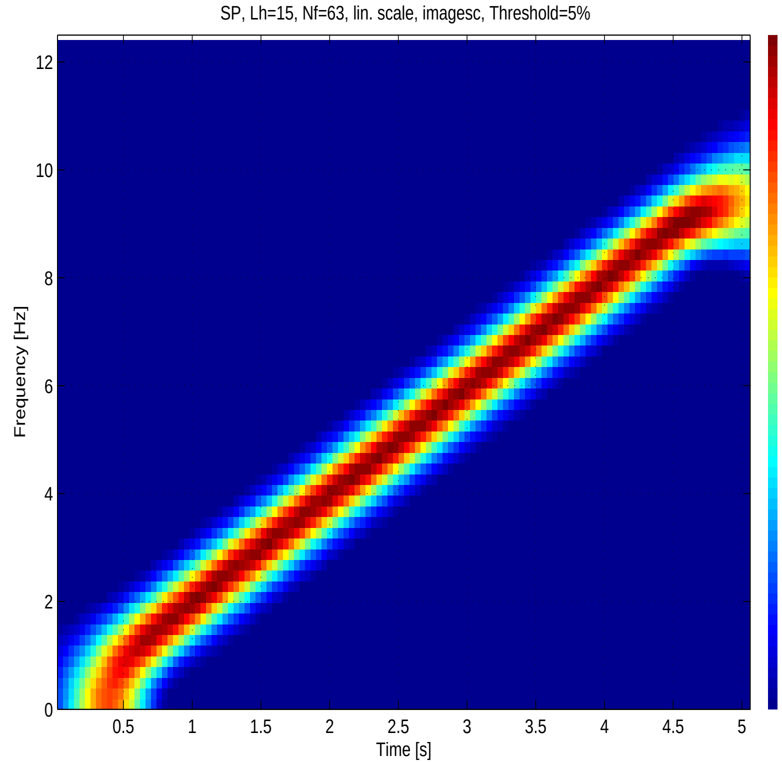
Candidate Ridge Selection Statistics

- Events should exceed some type of length criteria
- Events should exceed some expected power criteria signals.
- The setting of these threshold parameters is done by selecting an acceptable false alarm rate. This sets the power and length thresholding for the searches.

Sample Spectrograms

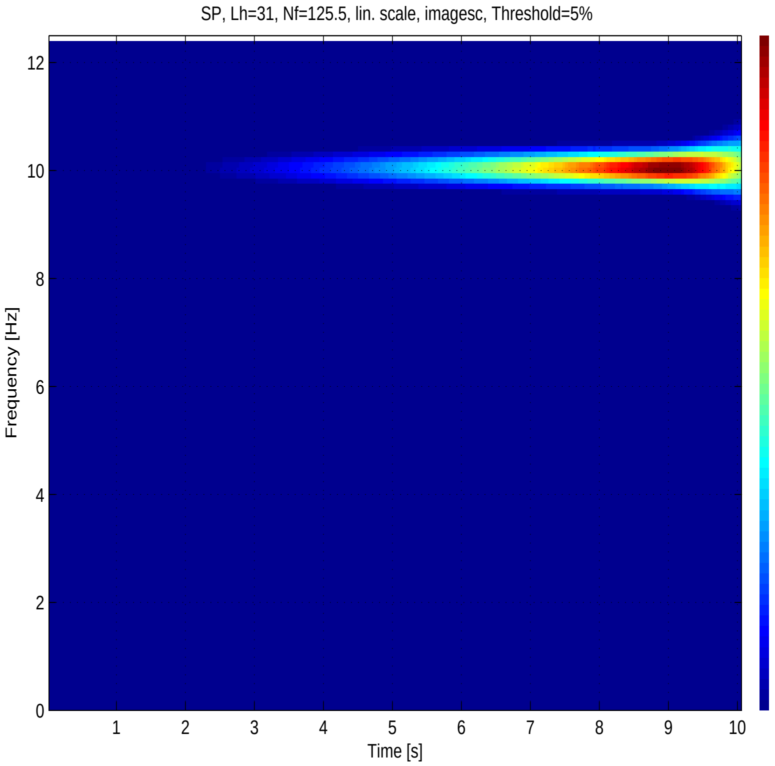


$$h(t) = A\sin(2\pi 10t)$$

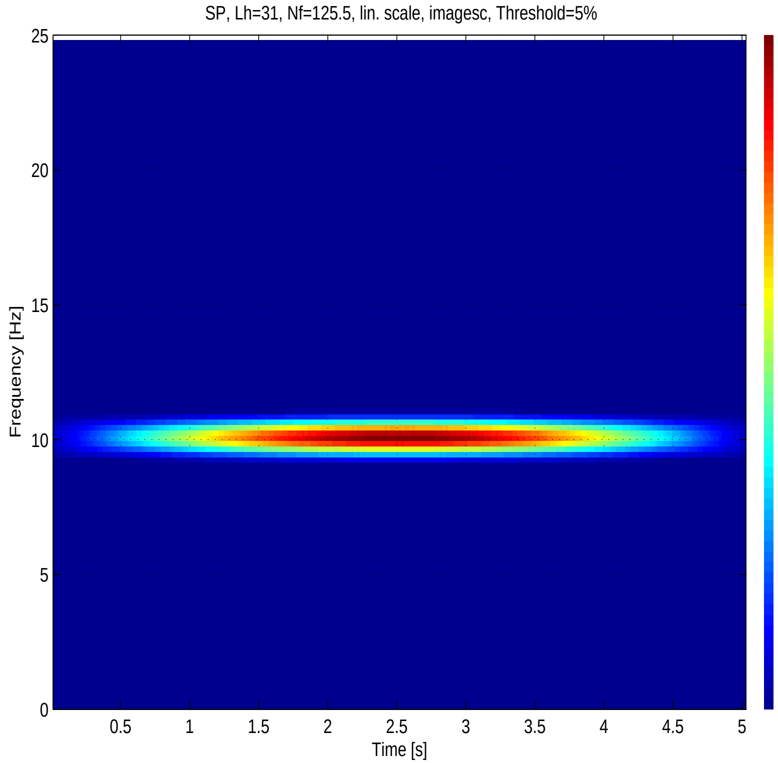


$$h(t) = A\sin(2\pi(2t)t)$$

Sample Spectrograms Continued



$$h(t) = t \sin(2\pi 10t)$$



$$h(t) = (10 - (t - \frac{t_f}{2})^2) \sin(2\pi 10t)$$

Acknowledgments

- The original LAL code “tracksearch” was written by R. Balasubramanian
- I contributed the ability to threshold tracksearch event curves via the curve’s accumulated power
- LDAS DSO patterned after Patrick Brady’s power DSO is under development
- Condor code, patterned after grid power code written by Patrick Brady, is under development
- We would like to thank the University of Wisconsin - Milwaukee for generously inviting us to come there and learn more about grid coding