Detecting a long-duration transient signal

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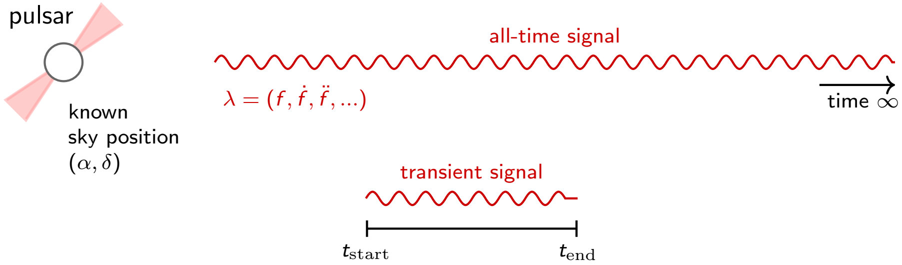
CONTINUOUS
GRAVITATIONAL
WAVES

Continuous wave signals



Transient CW-signal in the data

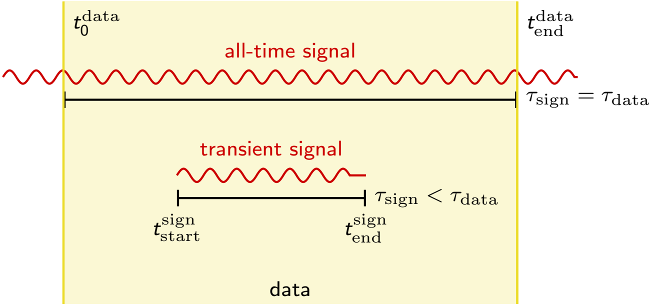
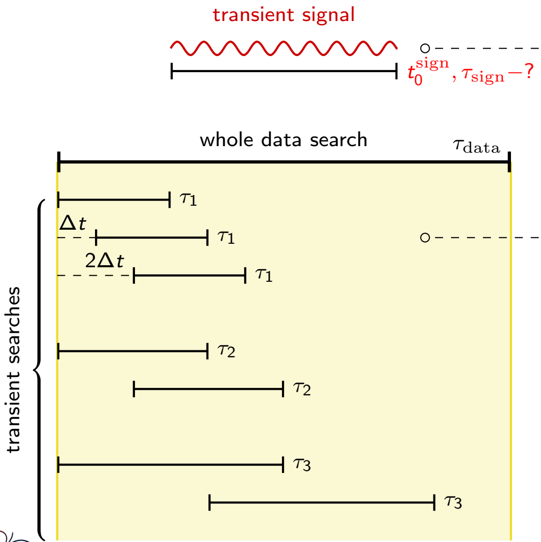


Figure: Scheme of various overlaps of a signal with the observing data.

Matched-filtering transient searches



Location in data and duration of the signal are unknown

Transient searches over various search spans and locations (step in the data).

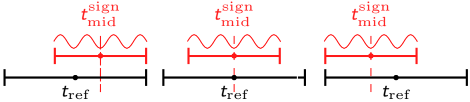
The search, which shows the best statistical result, is taken as the estimate of the signal's duration and location.

The orientation of the SNR-reduction ellipse

What to learn from the very initial search over all the data?

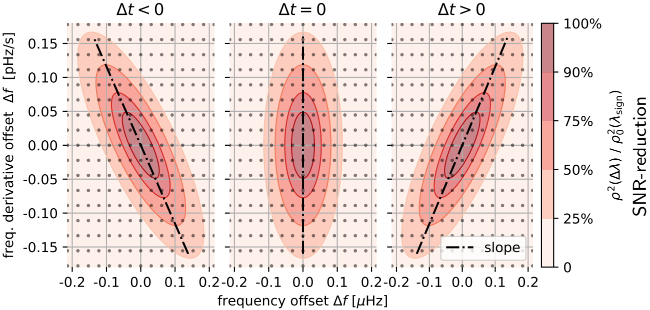
The orientation of the SNR-reduction ellipse

Transient signal
in data



$$\Delta t = t_{\mathrm{ref}} - t_{\mathrm{mid}}^{\mathrm{sign}}$$

All-data search
in frequency
and frequency
derivatives



the offsets from the signal parameters.

The inclination of the iso-overlap ellipse depends on the distance between the *reference time of the search* and the *mid-time of the signal* Δt.

Estimation of the middle time of a transient signal

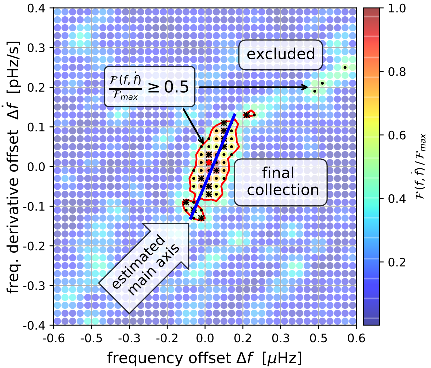
We assume there is a transient signal of unknown time-localisation in the data.

Estimation of the middle time of a signal

1. Perform a template search in frequency over all the available data in a thin phase parameter space around a candidate.
2. Find the main axis of the SNR-reduction profile from the search.
3. Estimate the signal mid-time from its slope:

$$t_{\mathrm{mid}}^{\mathrm{sign}\,*} = \frac{\Delta f(t_{\mathrm{ref}})}{\Delta \dot{f}(t_{\mathrm{ref}})} - t_{\mathrm{ref}} \qquad (1)$$

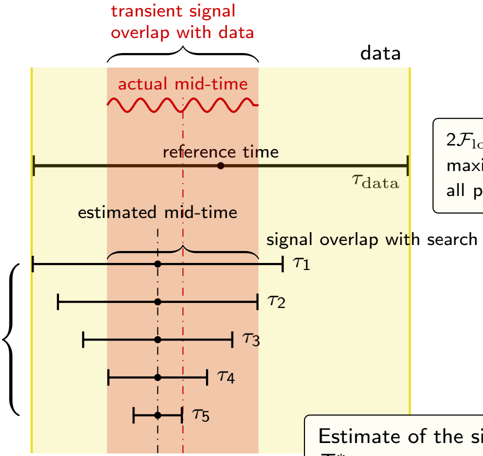
t_{ref} – the reference time of the search.



Post-following transient searches

All-data multi-template search in frequency and frequency derivatives

Post-following transient searches
Template searches over various time-intervals $\{T_i\}$ with the common reference time – the estimated mid-time of a signal.



$2\mathcal{F}_{\mathrm{loud}}\left(\mathcal{T}_i, \mathcal{T}_{\mathrm{sign}}\right)$ – the maximum $2\mathcal{F}$-value over all phase parameters.

Estimate of the signal duration
$T_i^* = \mathrm{argmax}_{\{T_i\}} \; [2\mathcal{F}_{\mathrm{loud}}\left(\mathcal{T}_i, \mathcal{T}_{\mathrm{sign}}\right)]$

Recovered signal duration from transient searches

Estimate of the signal duration

$$T_i^* = \underset{\{T_i\}}{\text{argmax}} \; [2\mathcal{F}_{\text{loud}}(\mathcal{T}_i, \mathcal{T}_{\text{sign}})], \quad (2)$$

In a simplified case, that is no noise and an infinitely fine grid in signal durations:

$$T_i^* = \underset{\{T_i\}}{\text{argmax}} \; [\rho^2_{\text{TS}}(\mathcal{T}_i, \mathcal{T}_{\text{sign}})], \quad (3)$$

and hence

$$T_i^* = \underset{\{T_i\}}{\text{argmax}} \left[\left(\frac{T^{\cap_i}_{\text{sign}}}{T_i} \right) \left(\frac{T^{\cap_i}_{\text{sign}}}{T_{\text{sign}}} \right) \right]. \quad (4)$$

where $T^{\cap_i}_{\text{sign}}$ is an intersection between the search $\mathcal{T}_i$ and the signal $\mathcal{T}_{\text{sign}}$.

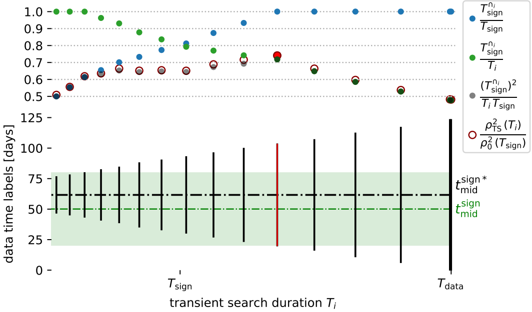


Figure: Illustration of how the estimate of the mid-time of a transient signal affects the SNR which in turn affects the estimate of the signal duration.

Computed errors from transient searches

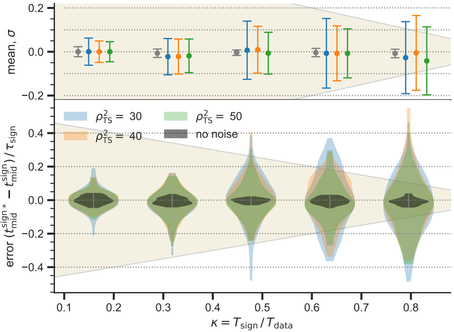


Figure: Violin plots for the distributions of the errors in the determination of the signal mid time from 100 injection-and-recovery searches at fixed SNR for signals of varying durations assuming realistic timestamps.

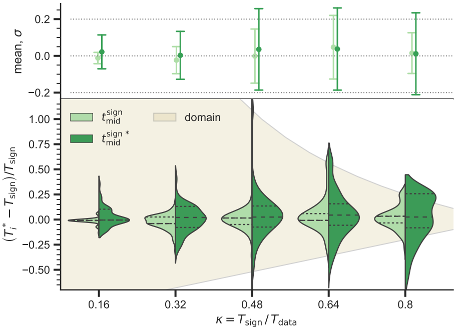


Figure: The left-side half-violins represent the recovered signal duration with $t_{\mathrm{mid}}^{\mathrm{sign}*} = t_{\mathrm{mid}}^{\mathrm{sign}}$. The right-side darker half-violins show the expected distribution in the absence of noise and for an infinitely fine grid. The right-side lighter half-violins show the recovered signal duration with the estimated mid-time $t_{\mathrm{mid}}^{\mathrm{sign}*}$.

Summary

We propose:

- Method to estimate the middle time of a transient signal, based on the slope of the iso-SNR-reduction profile ellipse of the all-time search.
- Search scheme useful when there are no EM observations to inform on the time of occurrence of the signal.

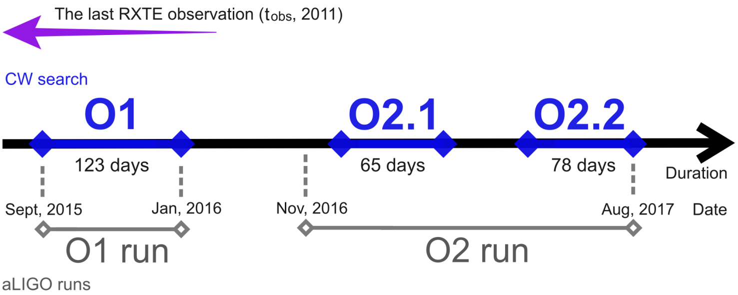
We computed:

- The errors in the signal mid-time estimate in the presence of the noise with the proposed method.
- The errors in the estimate of the signal's duration applying the post-following search method with.the mid-time estimate.

Future plans:

- We will compare the sensitivity of the proposed method of the follow-up searches with the matched-filtering transient searches. (Prix et al. (2011)).
- We intend to apply the proposed method to search for transient signals from the glitching pulsar J0537 in O1 and O2 LIGO runs, when there were no electromagnetic observations of the glitches. (Fesik and Papa (2020)).

The data input



- The data from **O1** and **O2** observing runs of the **Advanced LIGO** network.
- Three independent searches: **O1, O2.1, O2.2**.
- The template bank consists of $N_{\mathrm{templ}} \approx 10^{13}$ templates in $(f, \dot{f}, \ddot{f})$-space.
- A fully coherent search is performed for every template using a *matched filtering*.

The search output

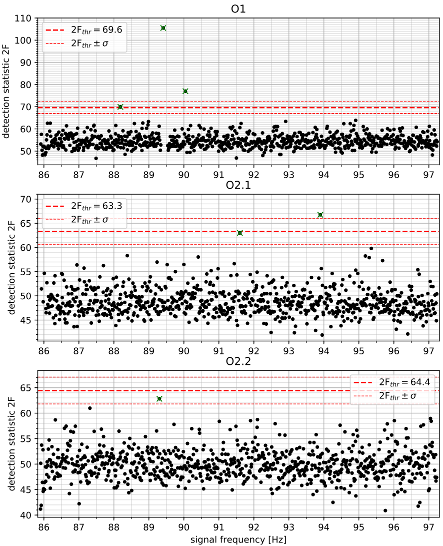


Figure: The most significant $2\mathcal{F}$ in every 0.014 Hz band.

The threshold for each search, $2\mathcal{F}_{\mathrm{thr}}$, is the expected highest detection statistic value in Gaussian noise over the number of independent templates searched.

f [Hz]	$\dot{f}$ [Hz/s]	$2\mathcal{F}$	$\frac{2\mathcal{F}-2\mathcal{F}_{\mathrm{thr}}}{\sigma}$
O1			
89.410489	-5.096×10^{-10}	105.50	13.65
90.044113	-3.753×10^{-10}	77.0	2.85
88.186443	-3.476×10^{-10}	69.91	0.16
O2.1			
93.898824	-5.358×10^{-10}	66.75	0.88
91.600806	-3.167×10^{-10}	63.00	-0.55
O2.2			
89.301451	-6.071×10^{-10}	62.82	-0.61

Table: The most significant candidates from each of the searches (Fesik and Papa, 2020).

References

L. Fesik and M. A. Papa. First Search for r-mode Gravitational Waves from PSR J0537–6910. *Astrophys. J.*, 895(1):11, 2020. doi: 10.3847/1538-4357/ab8193. [Erratum: Astrophys.J. 897, 185 (2020)].

R. Prix, S. Giampanis, and C. Messenger. Search method for long-duration gravitational-wave transients from neutron stars. *Phys. Rev.*, D84:023007, 2011. doi: 10.1103/PhysRevD.84.023007.

Thank you for your attention!