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Author(s): Carmichael, Joshua Daniel

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Dynamic Thresholds for STA/LTA Detectors that Output Templates

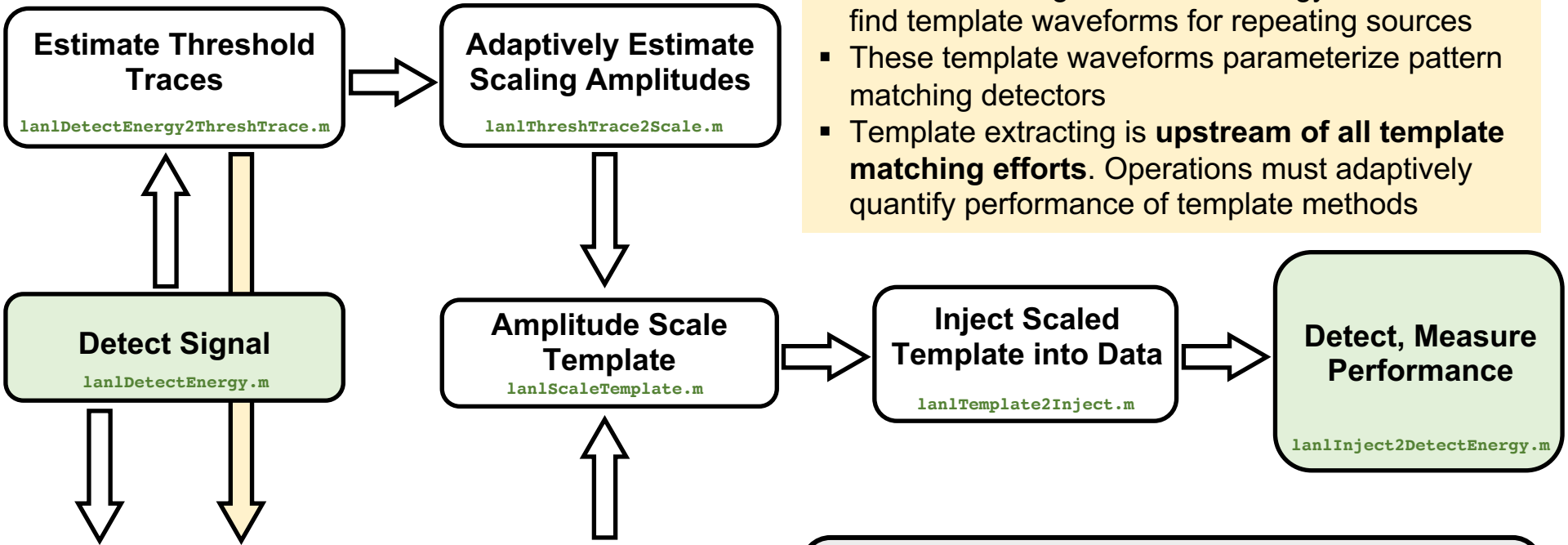
Joshua D Carmichael
Los Alamos National Laboratory

Aug 17, 2021 – Aug 18, 2021

GNDD Deliverable Working Group 6:
Status Update

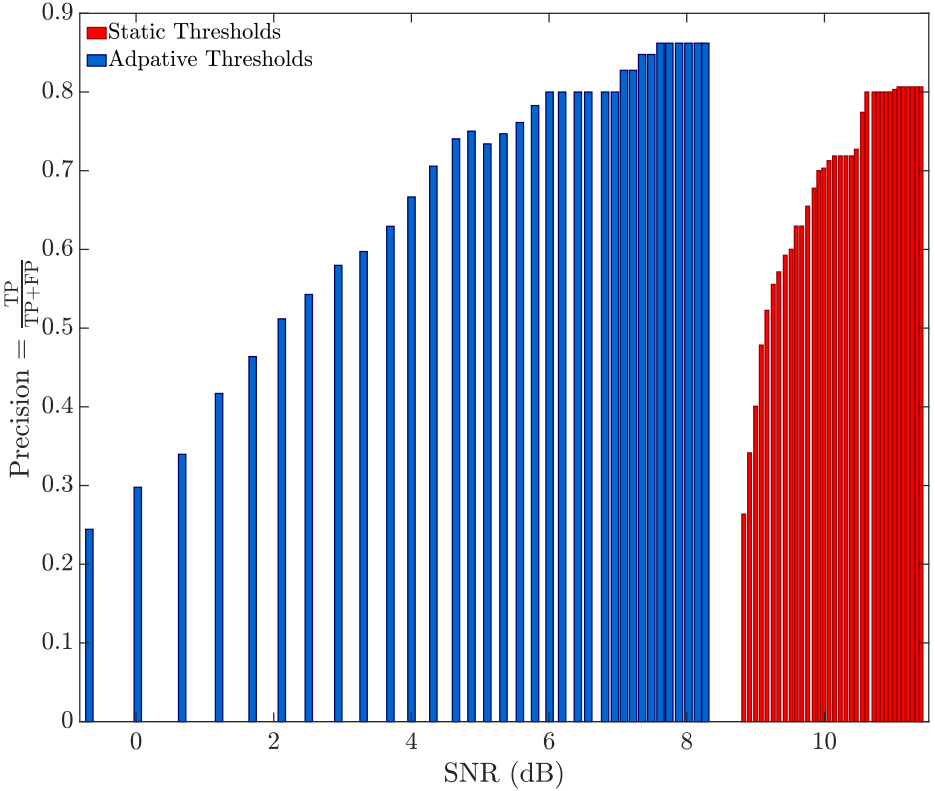
Bottom Line Up Front (BLUF) (1/2)

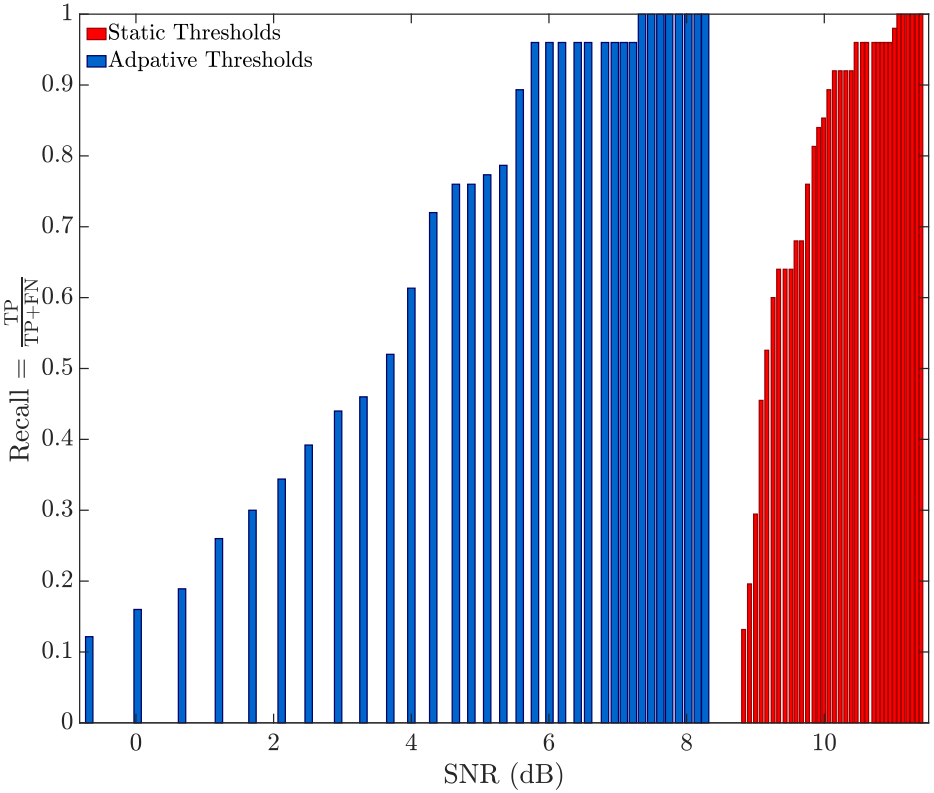
- Autonomous algorithms use energy detectors to find template waveforms for repeating sources
- These template waveforms parameterize pattern matching detectors
- Template extracting is **upstream of all template matching efforts**. Operations must adaptively quantify performance of template methods



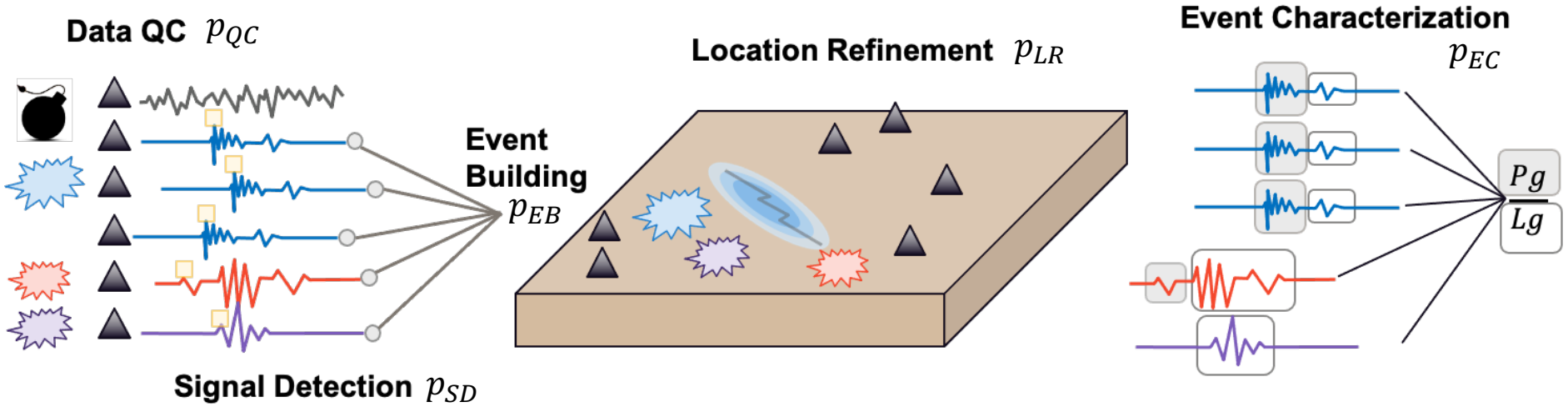
Updated LANL model for autonomous template-based detection and performance quantification and implementation with MATLAB ®

Bottom Line Up Front (BLUF) (2/2)





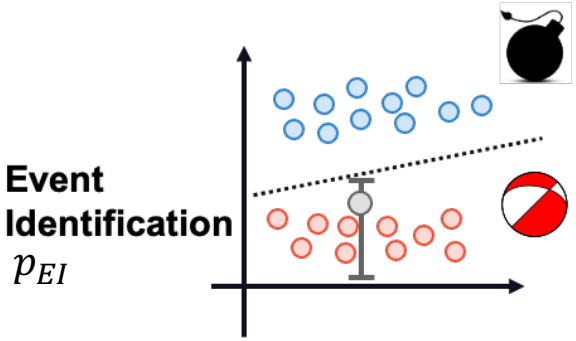
- The LANL **noise-adaptive signal detector** module clearly outperforms detectors with **static signal detector** thresholds. *The precision and recall at minimum SNR reflects background detection values*

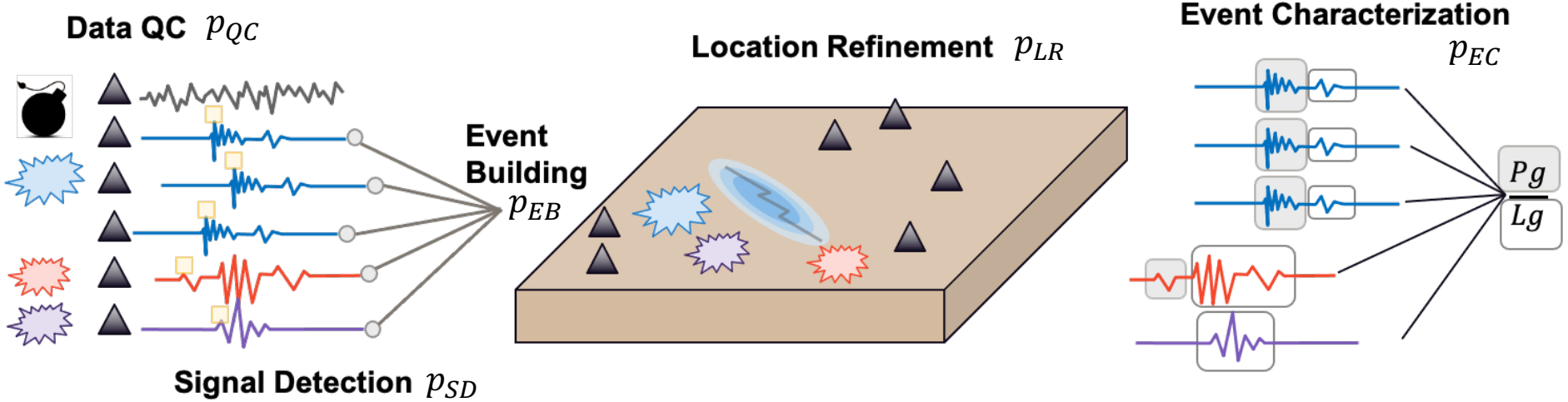


Monitoring function failure probability

$p_{MF,A}$ — Index of agent

Index for monitoring function





$$\Pr_F(\mathrm{EPP}) = 1 - \prod_{k=1}^{\text{Tasks}} \left(1 - \prod_{l=1}^{\text{Agents}} p_{kl}^{\text{Before}} \right)$$

Monitoring function failure probability

$p_{MF,A}$ — Index of agent

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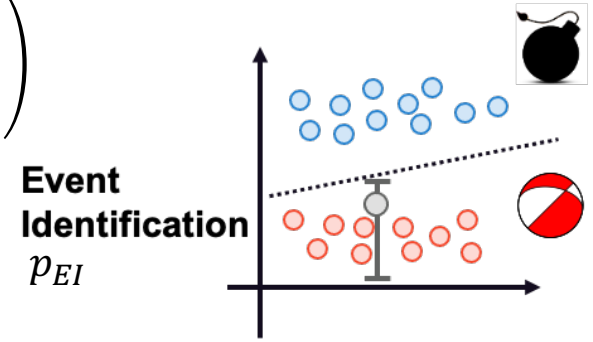

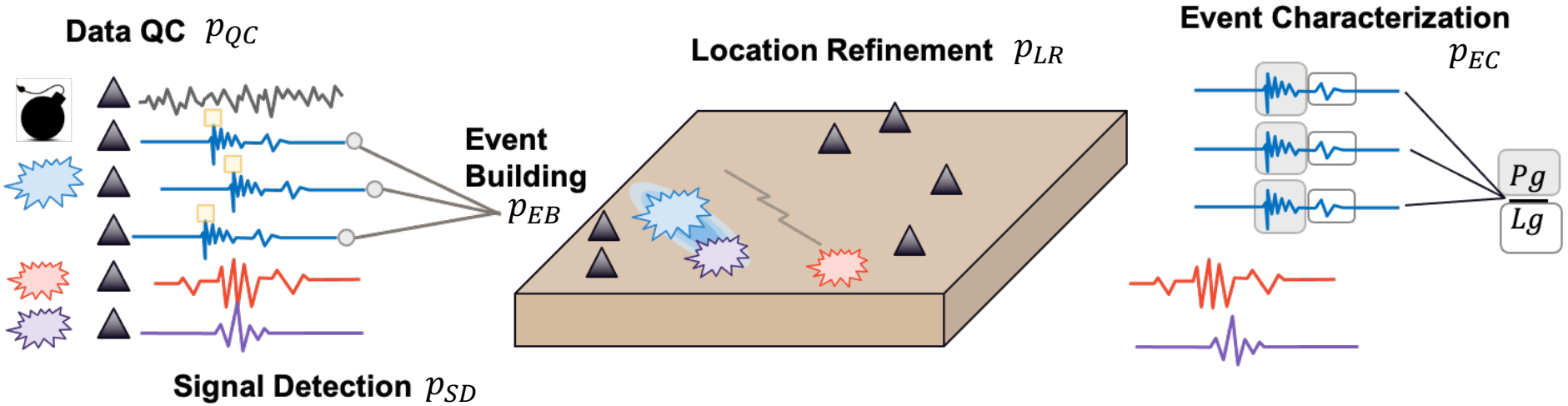

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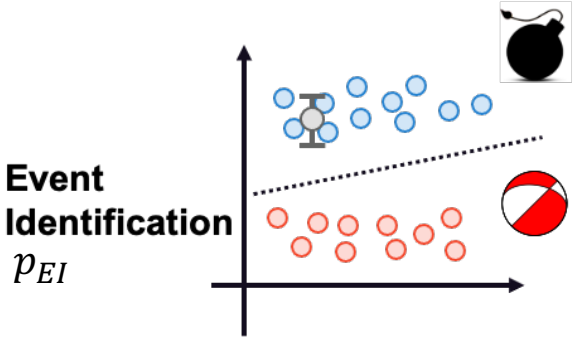
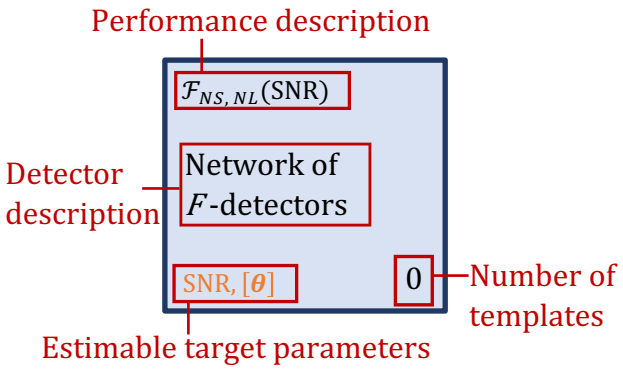
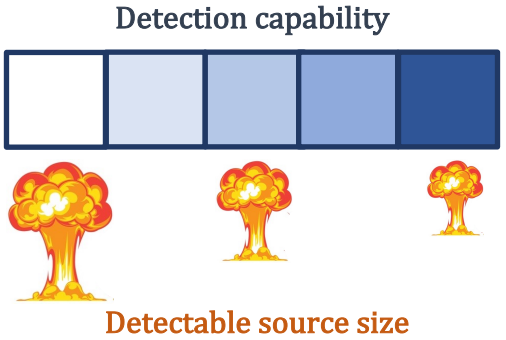


Number of templates

$\mathcal{F}_{CS,\,CL}(T \cdot \mathrm{SNR})$ Array-based subspace detectors $[\boldsymbol{A}]$ N	$\mathcal{F}_{NS,\,NL}(T \cdot \mathrm{SNR})$ Network-based subspace detectors $[\boldsymbol{A}]$ N	$\mathcal{F}_{NS,\,NL}(\mathrm{SNR}) \cdot \mathrm{CC}(\rho)$ Autonomous correlation detectors $[\mathrm{SNR}], [\boldsymbol{A}]$ N	$[\mathrm{CC}(\rho)]^T$ Bank of cone or correlation detectors $[\boldsymbol{A}]$ N
$\beta(\rho; \frac{1}{2}, \frac{1}{2}(S-1))$ Rayleigh wave/ polarization SNR, θ 1	$\chi^2_S\,(\mathrm{SNR})$ Envelope detectors A, ϕ 1-3	$\mathrm{Function}(\mathrm{CC}(\rho_\infty \rho))$ Cone detectors $A, [\boldsymbol{s}]$ 1-3	$\mathrm{CC}(\rho)$ Correlation detectors A 1-3
$\mathcal{F}_{S,\,L}(\mathrm{SNR})$ 1-3C STA/LTA SNR 0	$\mathcal{F}_{3S,\,3L}(\mathrm{SNR})$ Eigen- and Covariance DOA SNR, θ 0	$\mathcal{F}_{CS,\,CL}(\mathrm{SNR})$ Array beam/ F-detectors SNR, θ 0	$\mathcal{F}_{NS,\,NL}(\mathrm{SNR})$ Network of F-detectors $\mathrm{SNR}, [\boldsymbol{\theta}]$ 0

Template-target similarity & estimation precision





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$\mathcal{F}_{CS,\,CL}(T \cdot \mathrm{SNR})$ Array-based subspace detectors $[\boldsymbol{A}]$ N	$\mathcal{F}_{NS,\,NL}(T \cdot \mathrm{SNR})$ Network-based subspace detectors $[\boldsymbol{A}]$ N	$\mathcal{F}_{NS,\,NL}(\mathrm{SNR}) \cdot \mathrm{CC}(\rho)$ Autonomous correlation detectors $[\mathrm{SNR}], [\boldsymbol{A}]$ N	$[\mathrm{CC}(\rho)]^T$ Bank of cone or correlation detectors $[\boldsymbol{A}]$ N
$\beta(\rho; \frac{1}{2}, \frac{1}{2}(S-1))$ Rayleigh wave/ polarization SNR, θ 1	$\chi^2_S\ (\mathrm{SNR})$ Envelope detectors A, ϕ 1-3	$\mathrm{Function}(\mathrm{CC}(\rho_\infty \rho))$ Cone detectors $A, [\boldsymbol{s}]$ 1-3	$\mathrm{CC}(\rho)$ Correlation detectors A 1-3
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Template-target similarity & estimation precision

Template-reliant detectors

Performance description

$\mathcal{F}_{NS,\,NL}(\mathrm{SNR})$

Detector description

Network of F-detectors

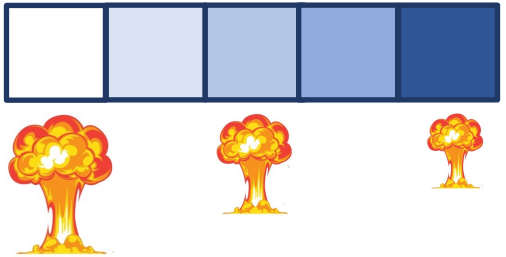
$\mathrm{SNR}, [\boldsymbol{\theta}]$

0

Number of templates

Estimable target parameters

Detection capability



Detectable source size

Number of templates

$\mathcal{F}_{CS,\,CL}(T \cdot \mathrm{SNR})$ Array-based subspace detectors [$\boldsymbol{A}$] N	$\mathcal{F}_{NS,\,NL}(T \cdot \mathrm{SNR})$ Network-based subspace detectors [$\boldsymbol{A}$] N	$\mathcal{F}_{NS,\,NL}(\mathrm{SNR}) \cdot \mathrm{CC}(\rho)$ Autonomous correlation detectors [SNR], [$\boldsymbol{A}$] N	$[\mathrm{CC}(\rho)]^T$ Bank of cone or correlation detectors [$\boldsymbol{A}$] N
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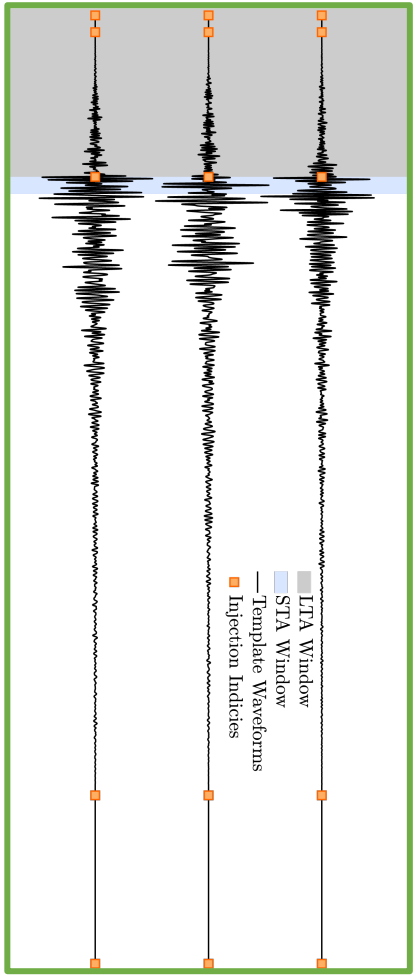
Template-target similarity & estimation precision

Energy Detectors Enable Template-reliant detectors



- Autonomous algorithms use energy detectors to find template waveforms that represent repeating sources
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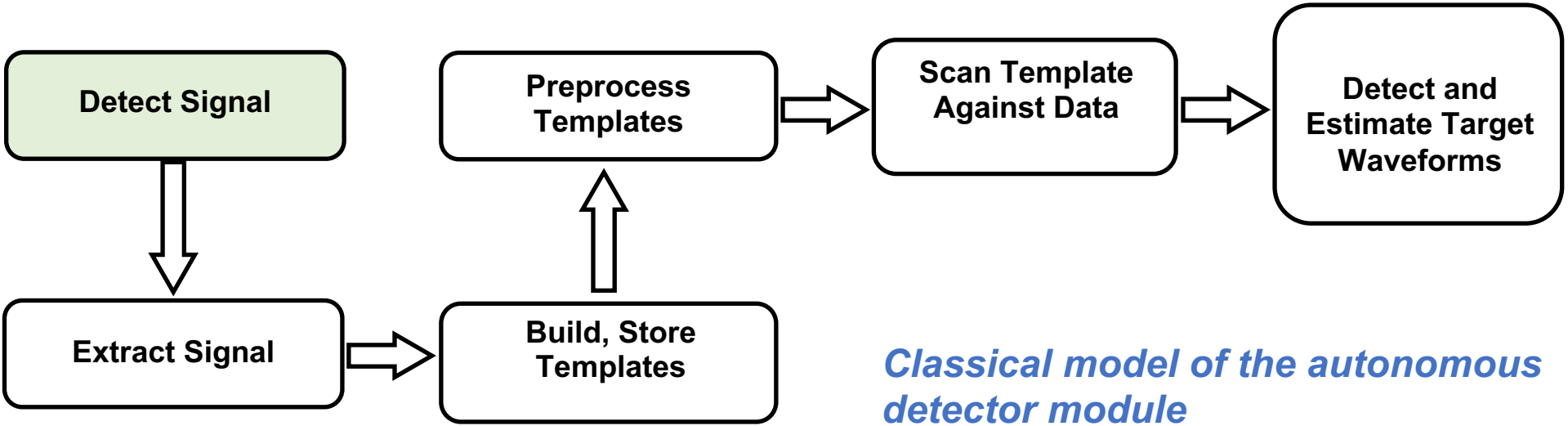
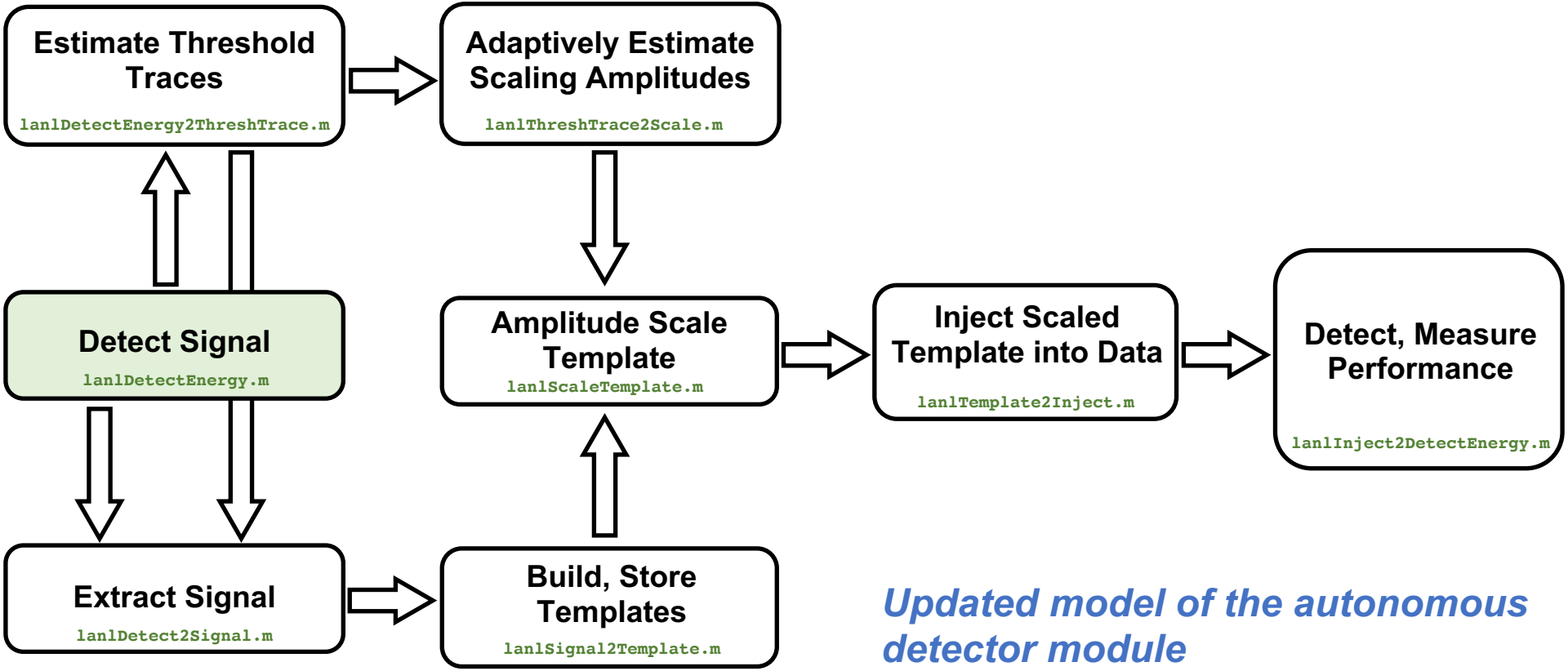
- Template extracting is **upstream of all template matching efforts**. Operations must adaptively quantify performance of template-extraction methods.

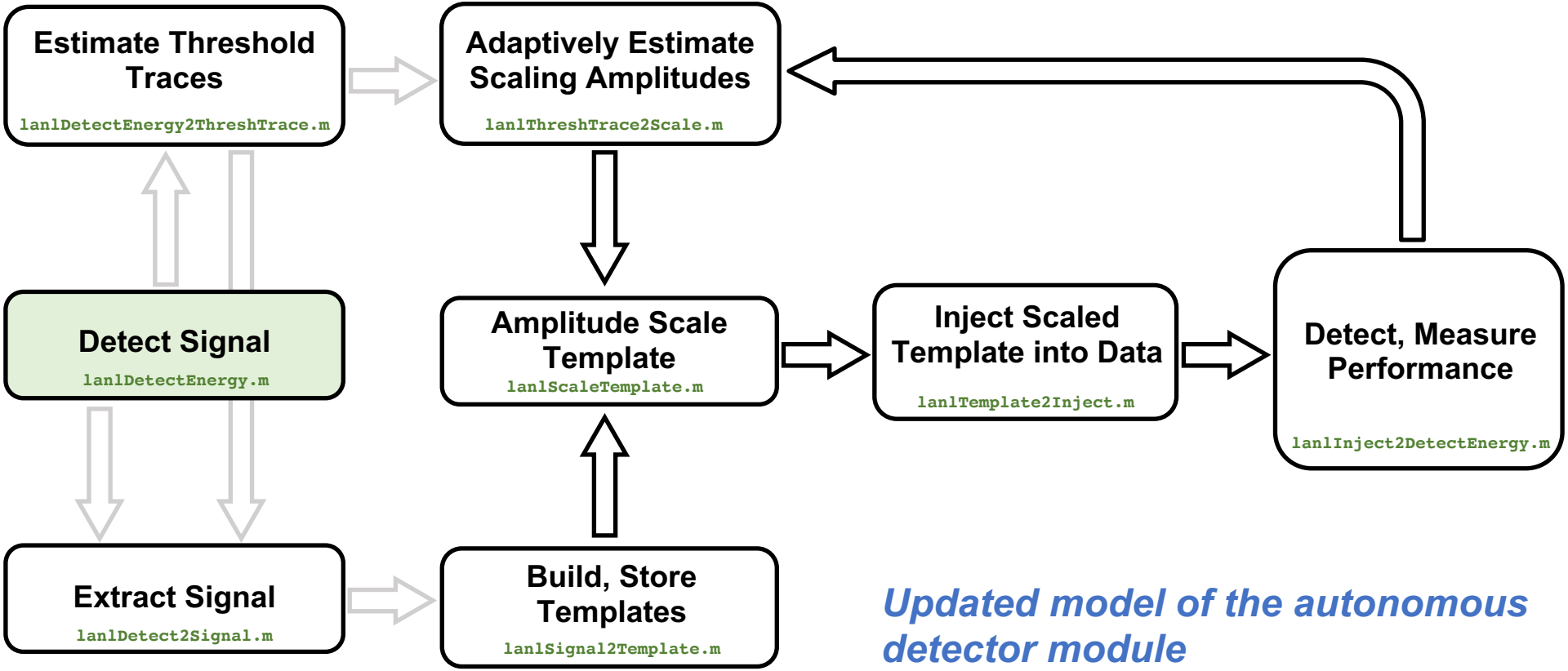


Classical model of the autonomous detector module



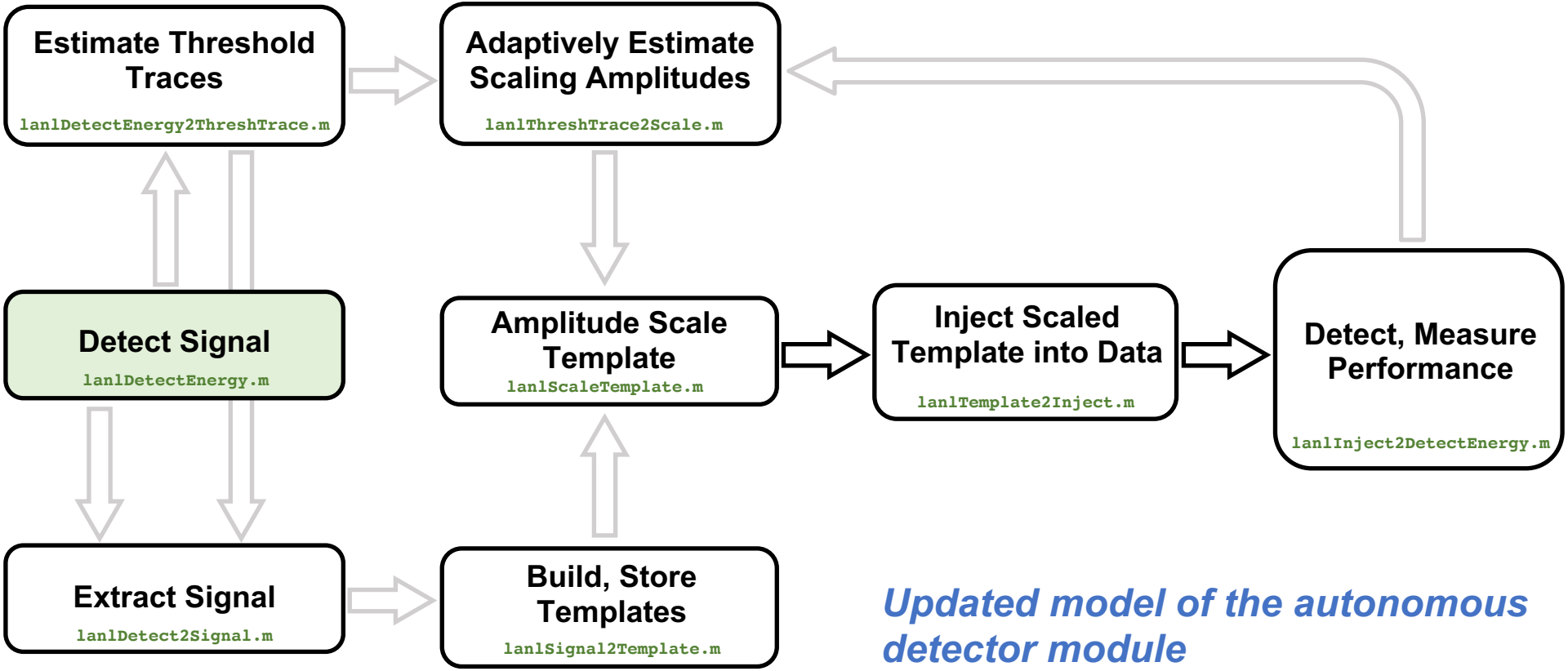
Updated model of the autonomous detector module

`Iteration == 1`



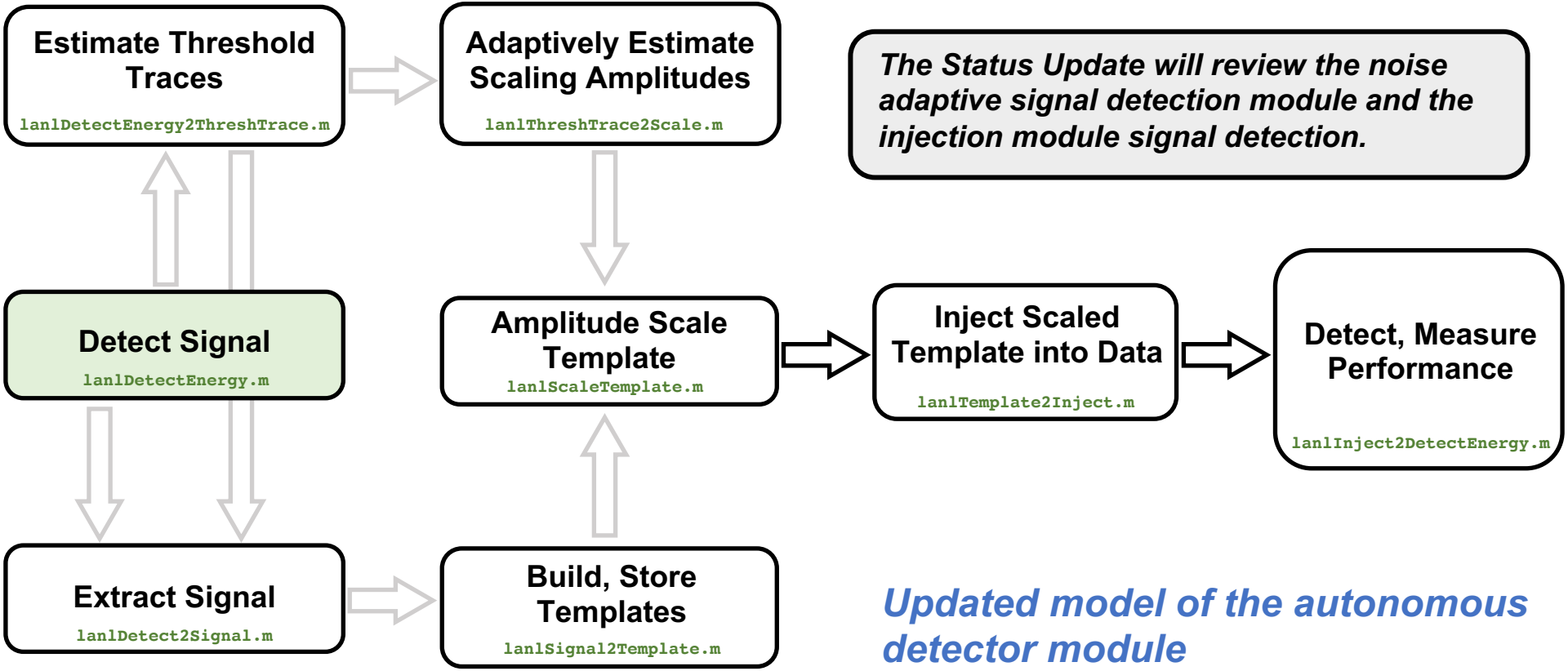
Updated model of the autonomous detector module

Iteration >= 1



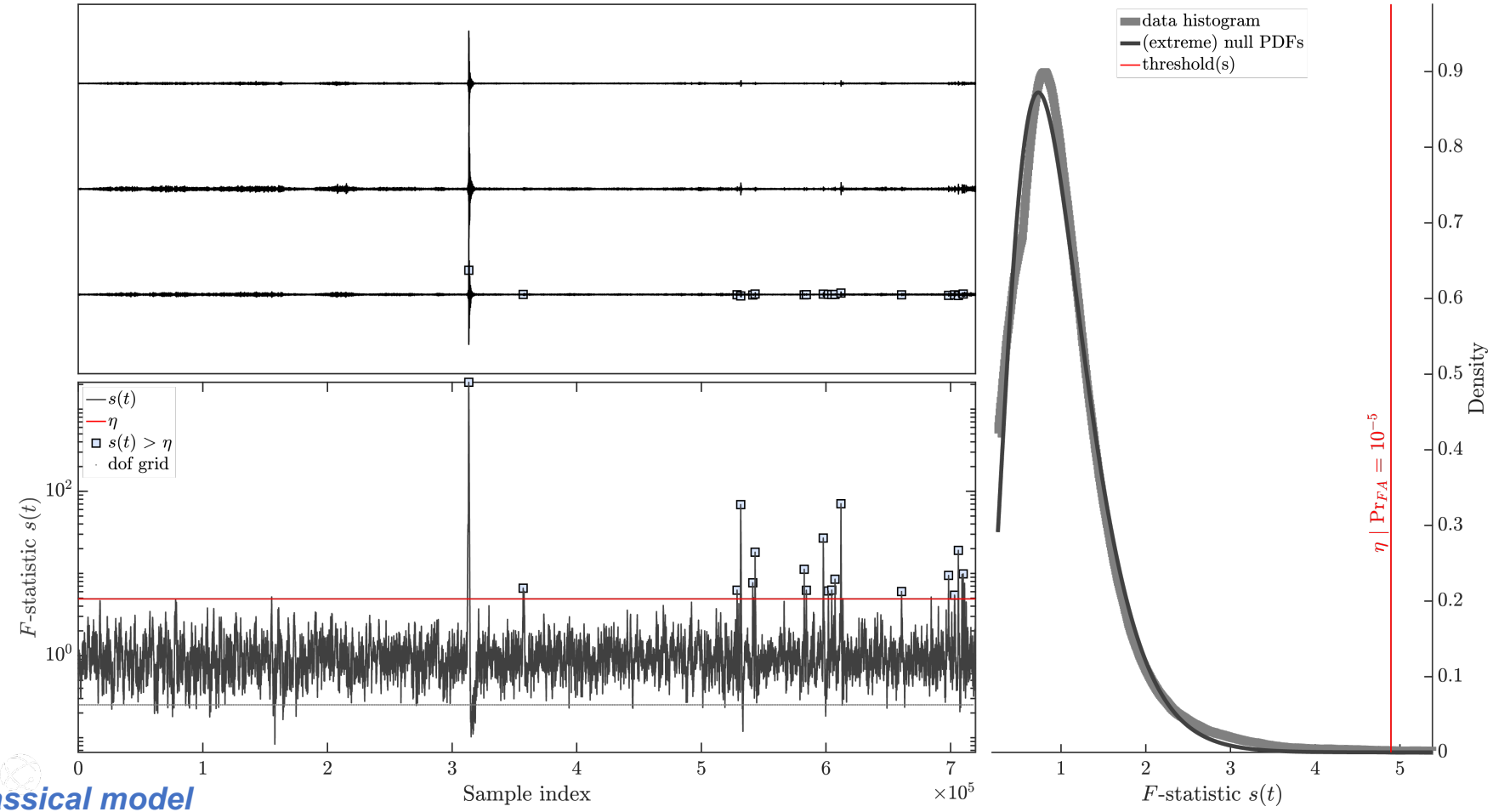
Updated model of the autonomous detector module

Iteration END

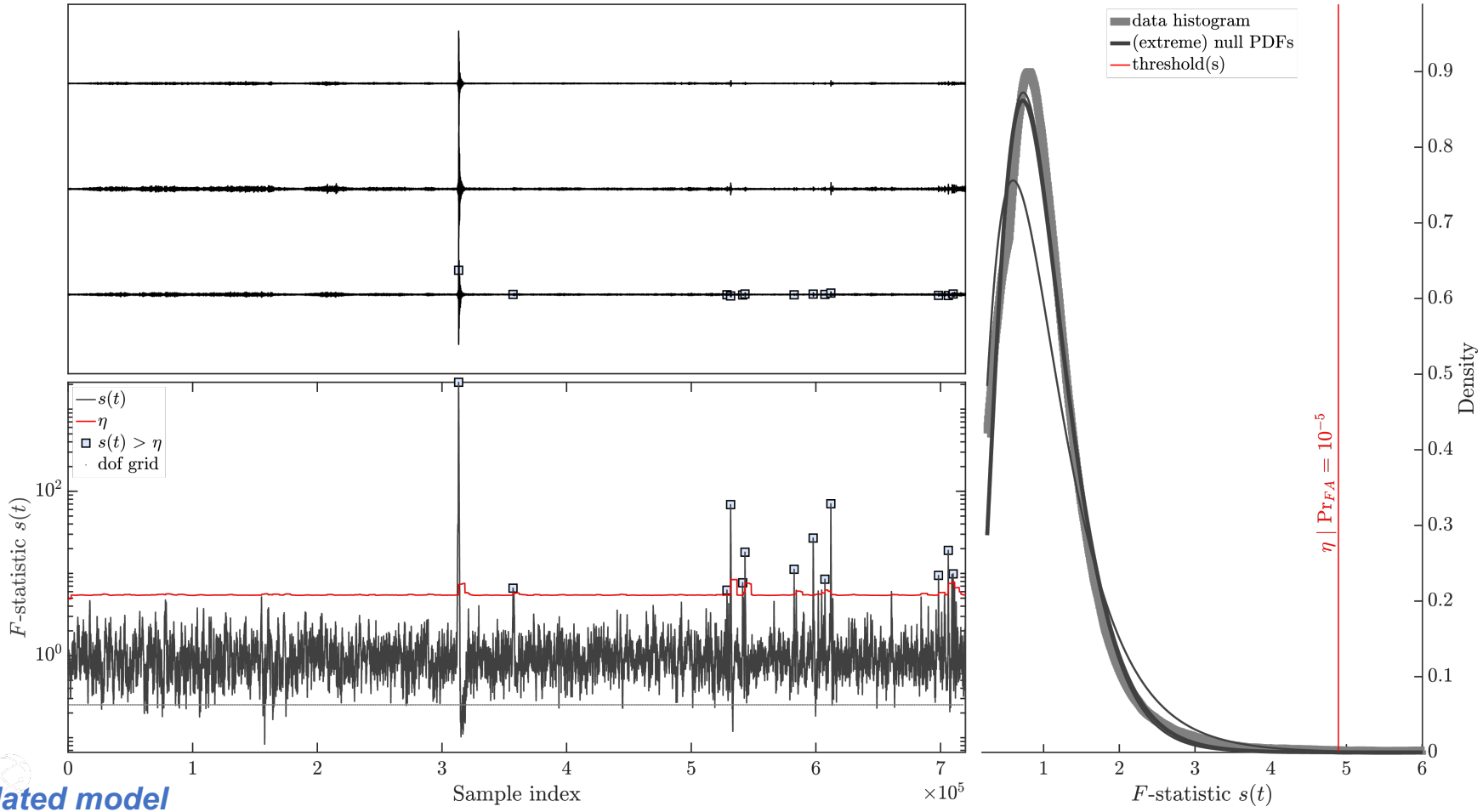


The Status Update will review the noise adaptive signal detection module and the injection module signal detection.

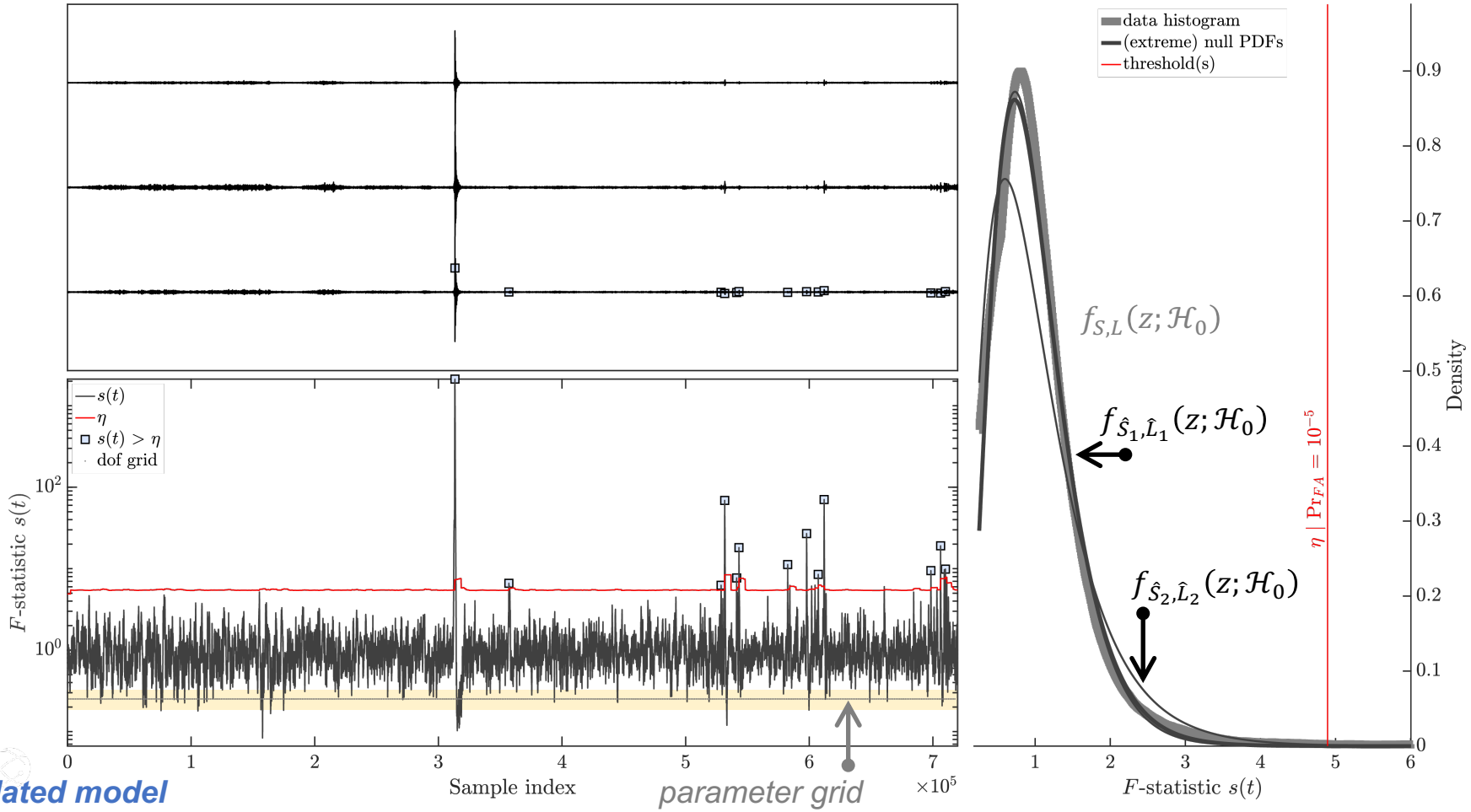
Updated model of the autonomous detector module



Classical model

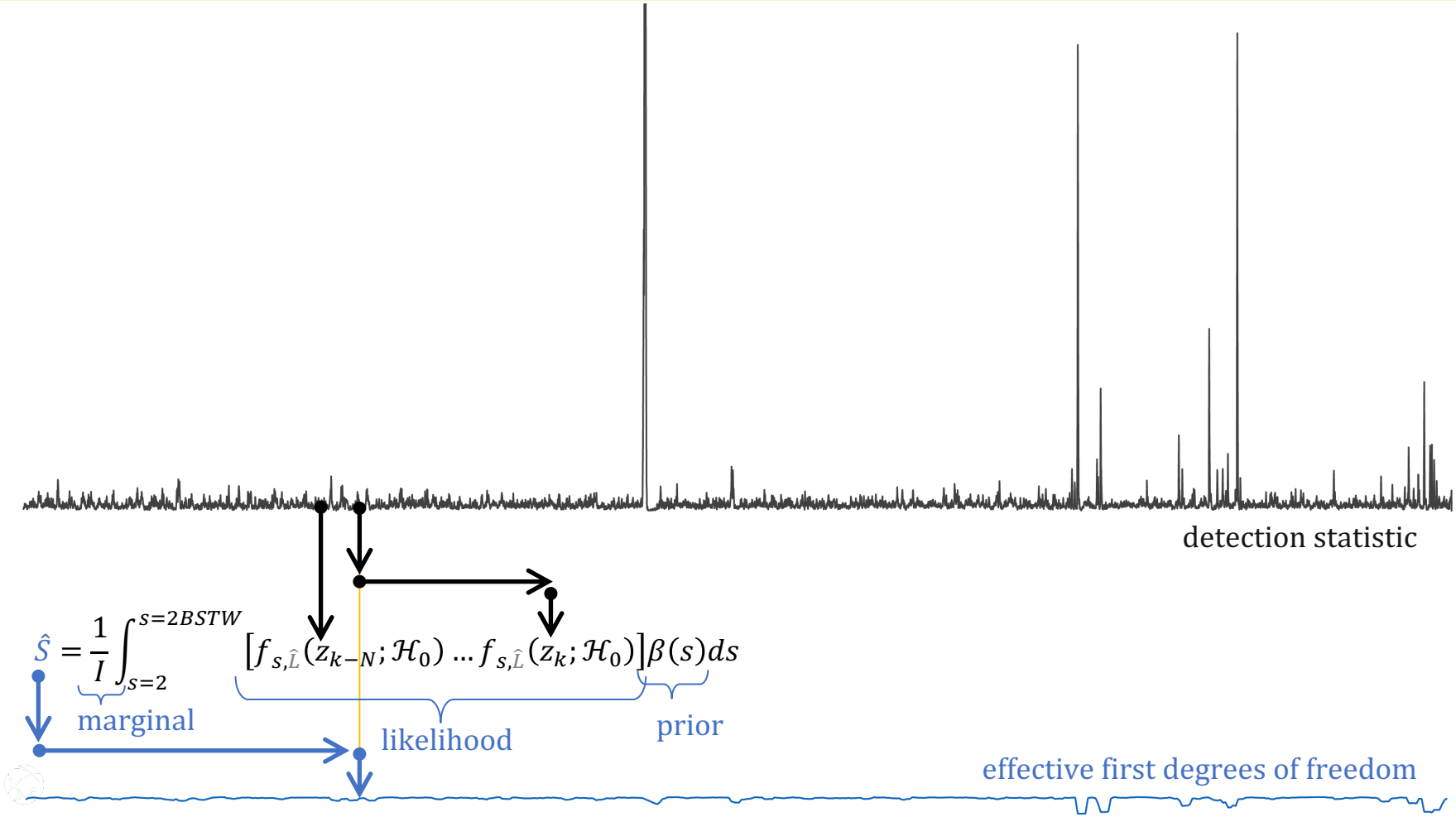


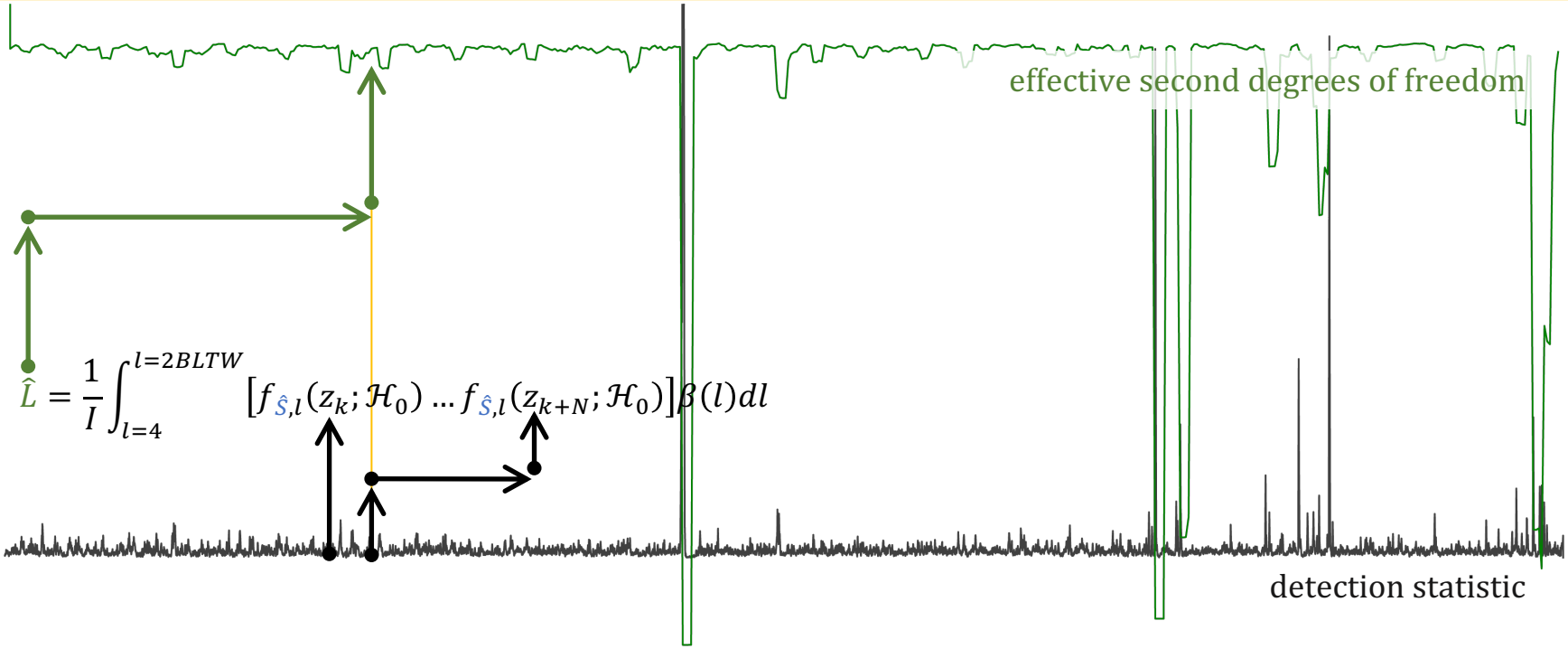
updated model



updated model

parameter grid

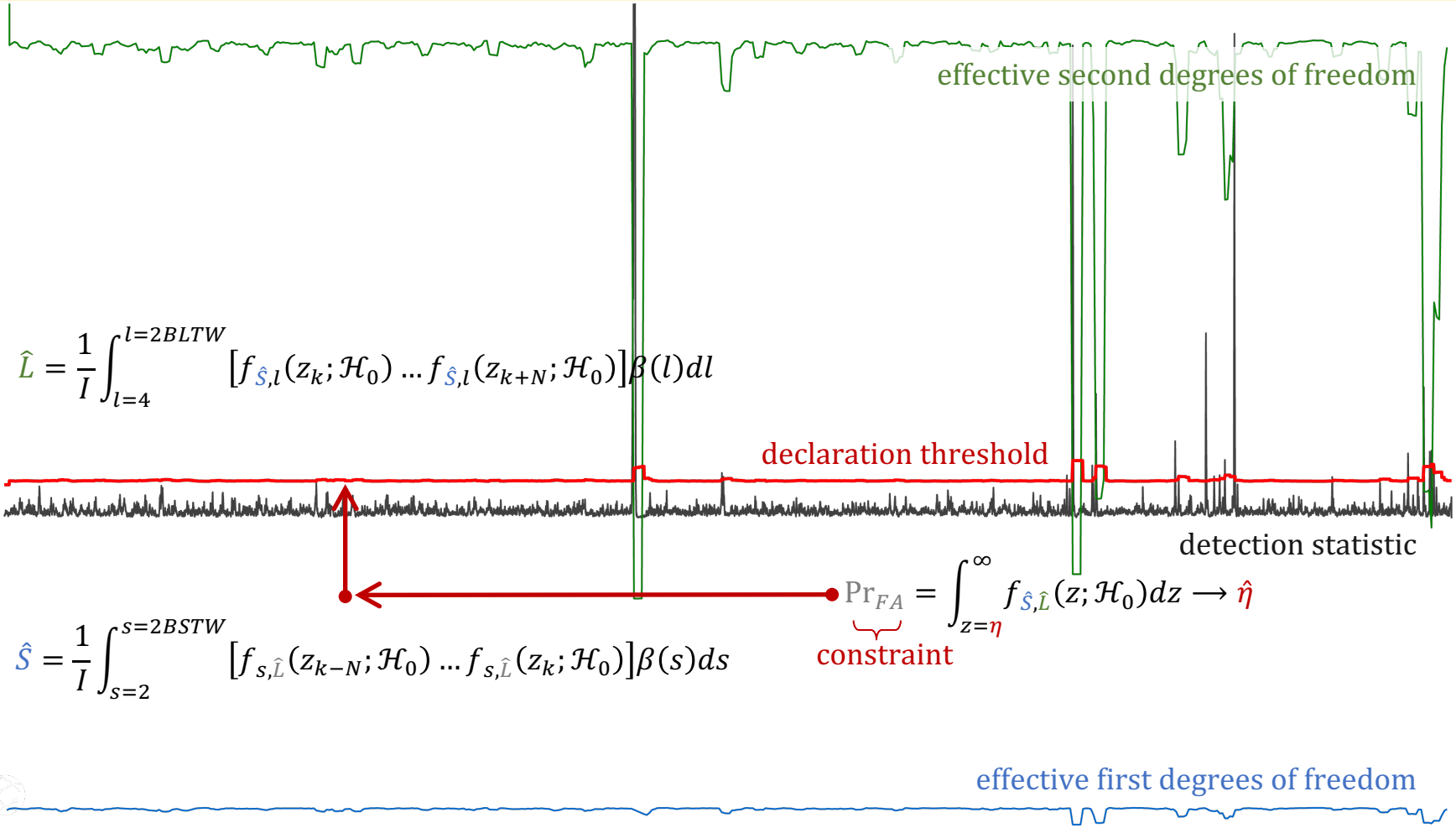

detection statistic
$\hat{S} = \frac{1}{I}\int_{s=2}^{s=2BSTW} [f_{s,\hat{L}}(z_{k-N};\mathcal{H}_0) \dots f_{s,\hat{L}}(z_k;\mathcal{H}_0)]\beta(s)ds$
marginal
likelihood
prior
effective first degrees of freedom

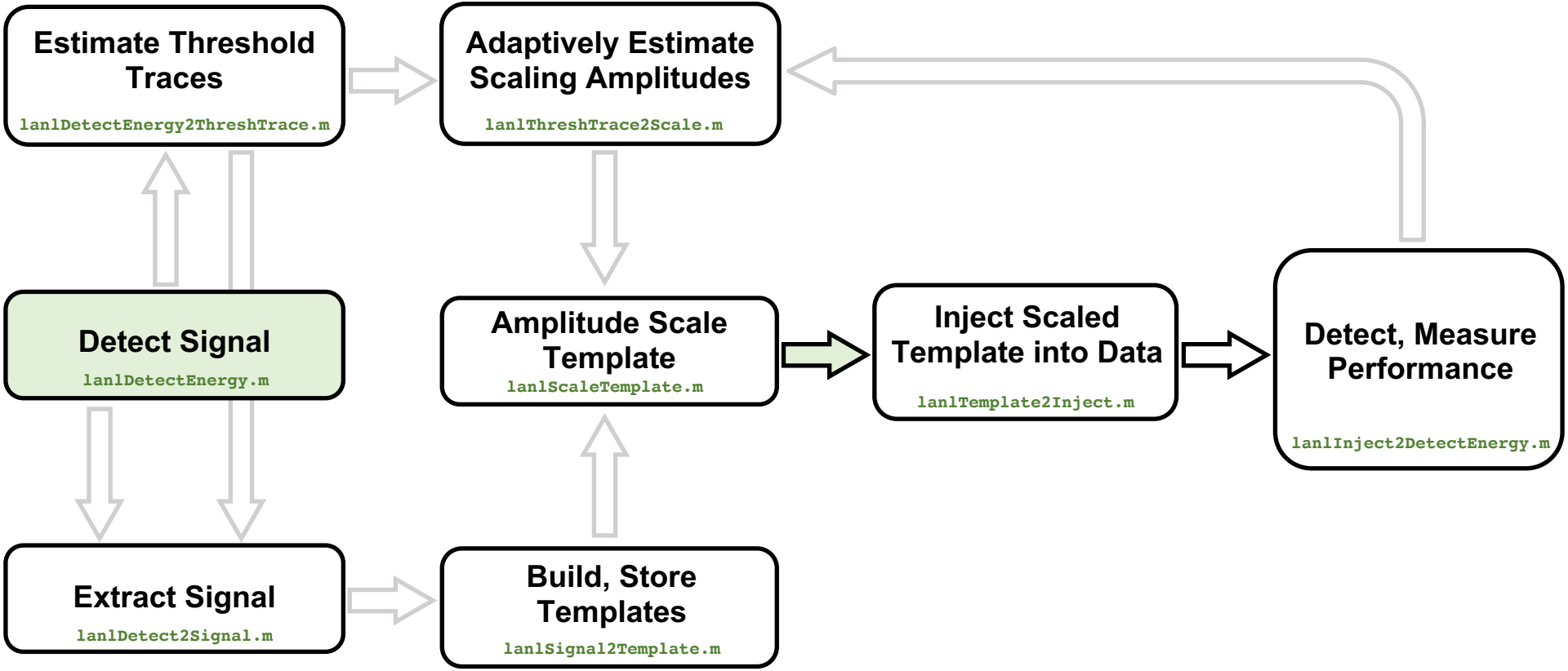


$$\hat{L} = \frac{1}{I}\int_{l=4}^{l=2BLTW} \left[f_{\hat{S},l}(z_k;\mathcal{H}_0) \dots f_{\hat{S},l}(z_{k+N};\mathcal{H}_0)\right]\beta(l)dl$$

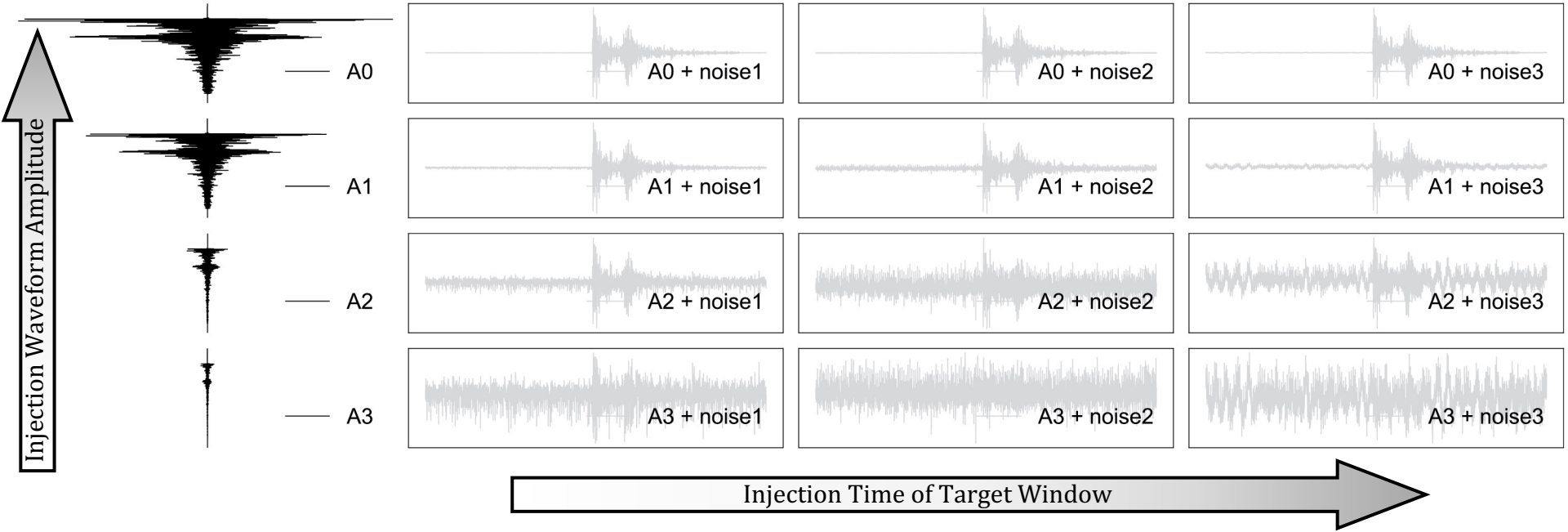
$$\hat{S} = \frac{1}{I}\int_{s=2}^{s=2BSTW} \left[f_{s,\hat{L}}(z_{k-N};\mathcal{H}_0) \dots f_{s,\hat{L}}(z_k;\mathcal{H}_0)\right]\beta(s)ds$$

effective first degrees of freedom


effective second degrees of freedom
$\hat{L} = \frac{1}{I}\int_{l=4}^{l=2BLTW} [f_{\hat{S},l}(z_k;\mathcal{H}_0) \dots f_{\hat{S},l}(z_{k+N};\mathcal{H}_0)]\beta(l)dl$
declaration threshold
detection statistic
$\Pr_{FA} = \int_{z=\eta}^{\infty} f_{\hat{S},\hat{L}}(z;\mathcal{H}_0)dz \longrightarrow \hat{\eta}$
constraint
$\hat{S} = \frac{1}{I}\int_{s=2}^{s=2BSTW} [f_{s,\hat{L}}(z_{k-N};\mathcal{H}_0) \dots f_{s,\hat{L}}(z_k;\mathcal{H}_0)]\beta(s)ds$
effective first degrees of freedom

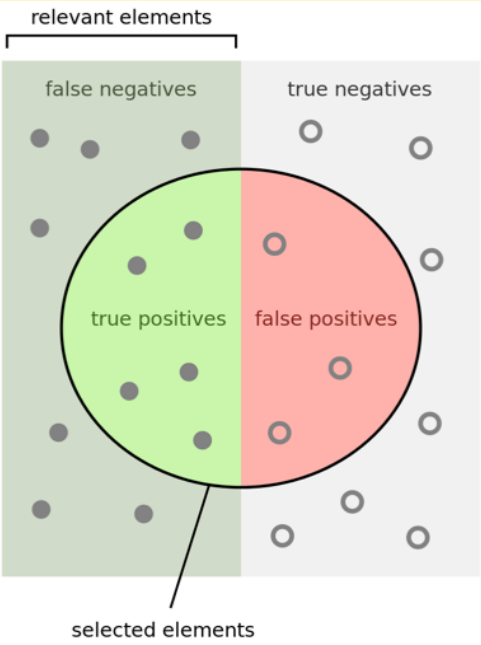


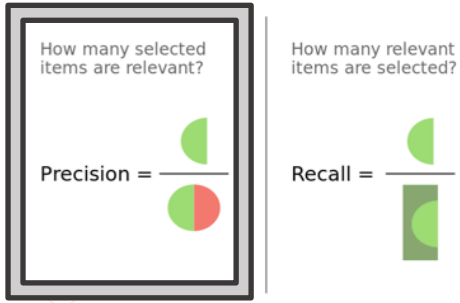
Iteration END

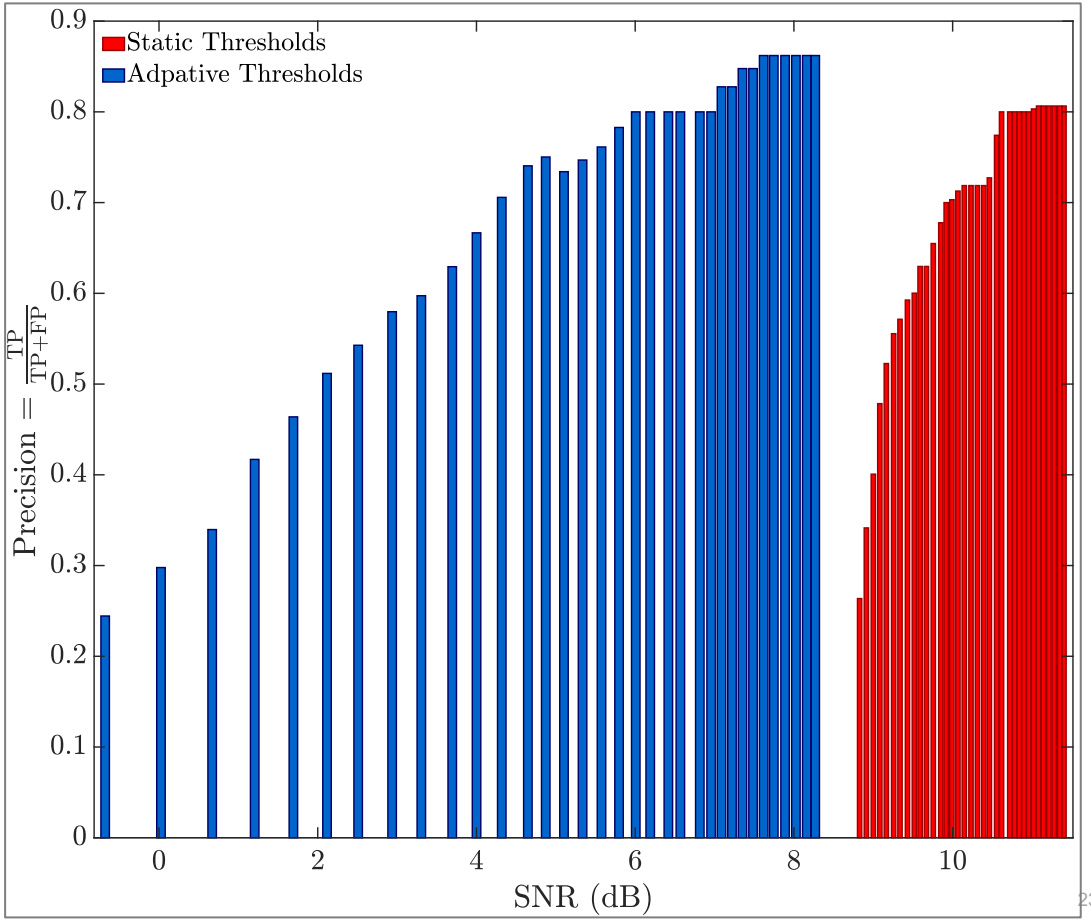


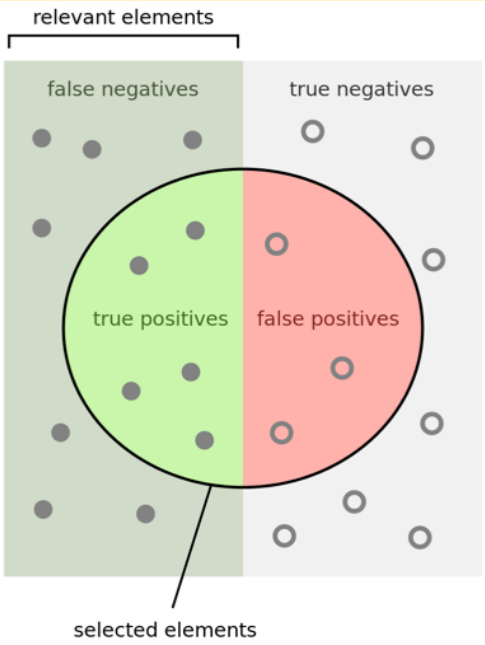
- Autonomous algorithm within module injects amplitude-scaled waveforms into a two-dimensional grid indexed by SNR/amplitude and noise/time
- Performance algorithm inputs priori knowledge of injection amplitude and injection time into Bayesian adaptive detector
- Performance algorithm outputs empirical and predicted **precision and recall** over SNR and time grid

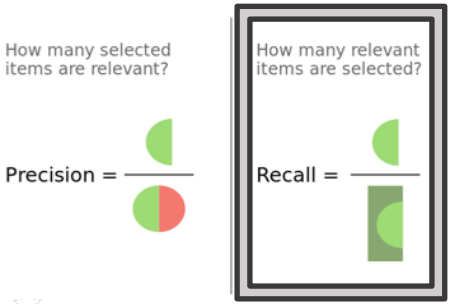
Figure authored by Richard Alfaro-Diaz (LANL)

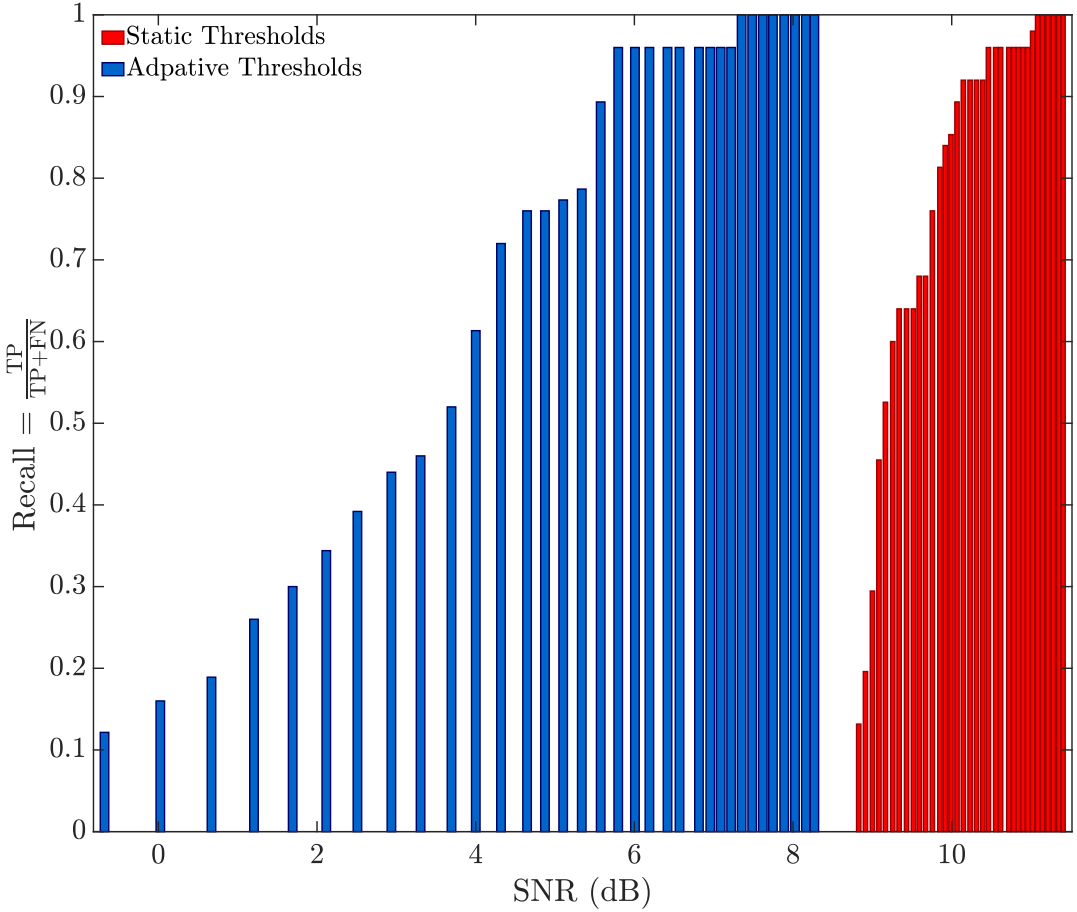

relevant elements
false negatives
true negatives
true positives
false positives
selected elements

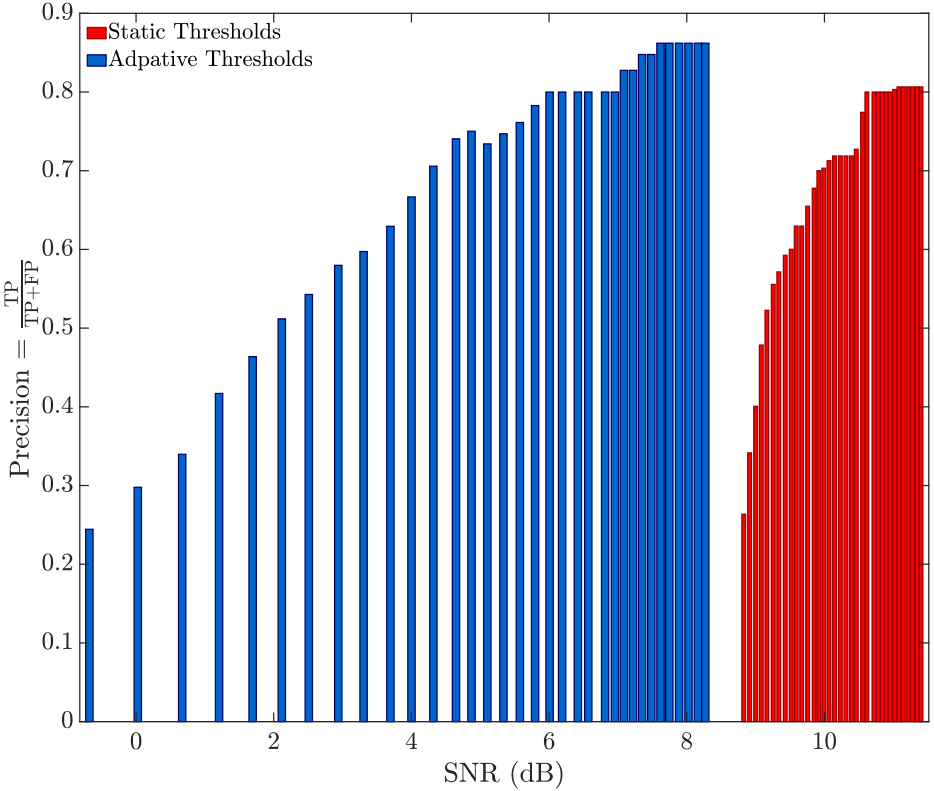

How many selected items are relevant?
Precision =
How many relevant items are selected?
Recall =

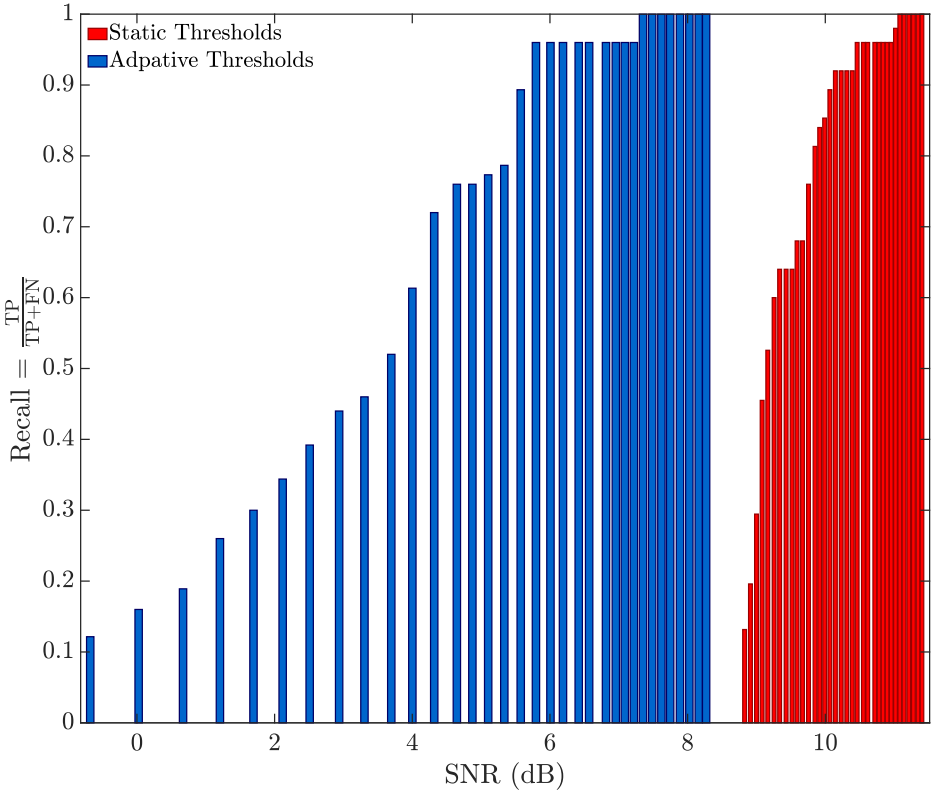

Static Thresholds
Adpative Thresholds
Precision = TP/(TP+FP)
SNR (dB)
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
0
2
4
6
8
10


relevant elements
false negatives
true negatives
true positives
false positives
selected elements


How many selected items are relevant?
Precision =
How many relevant items are selected?
Recall =

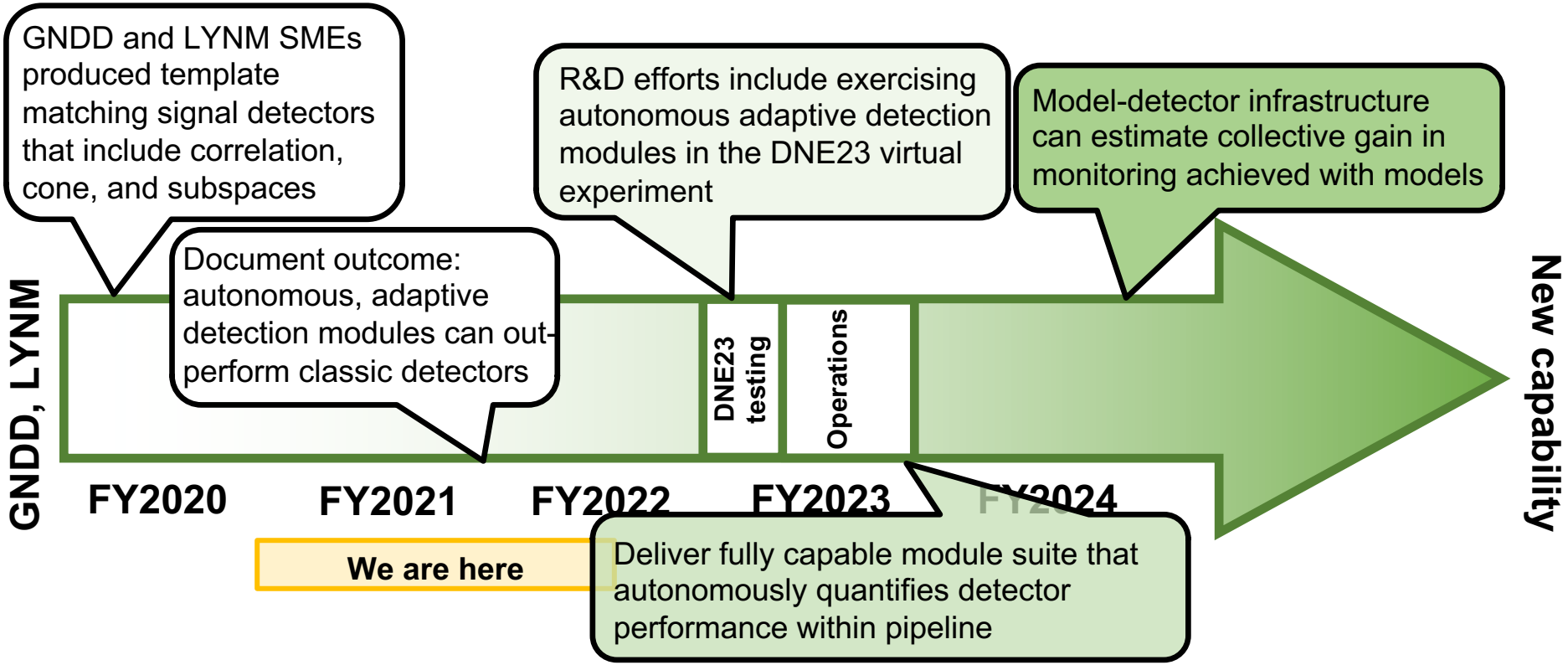

Static Thresholds
Adpative Thresholds
Recall = TP/(TP+FN)
SNR (dB)
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
0
2
4
6
8
10





- The LANL **noise-adaptive signal detector** module clearly outperforms detectors with **static signal detector** thresholds. *The precision and recall at minimum SNR reflects background detection values*

Milestones of Autonomous Detection and Outlook



Questions?