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Detection of Uncertain Seismic Signals

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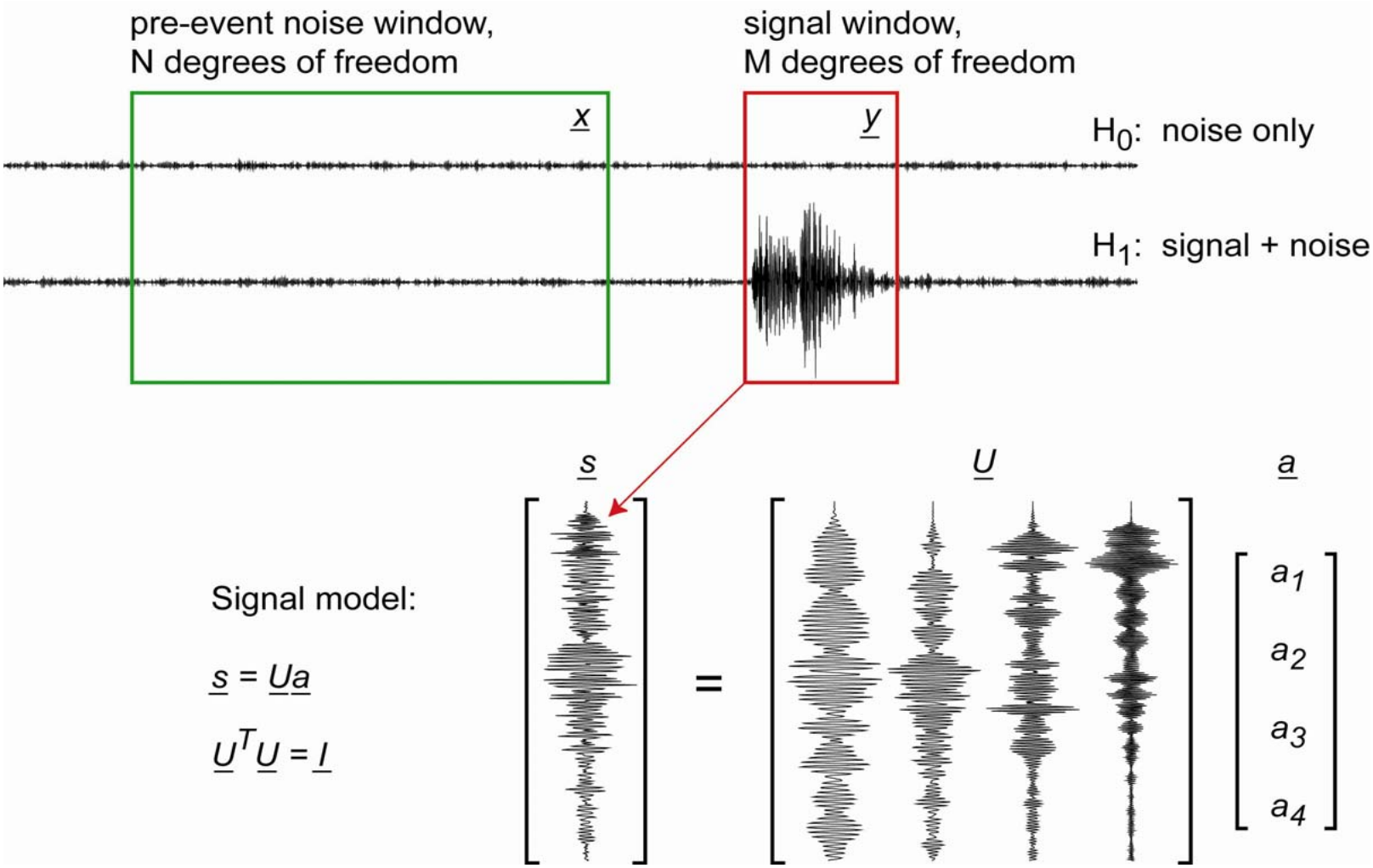
Current seismic detection practice is concentrated at the extremes of a spectrum of possibilities

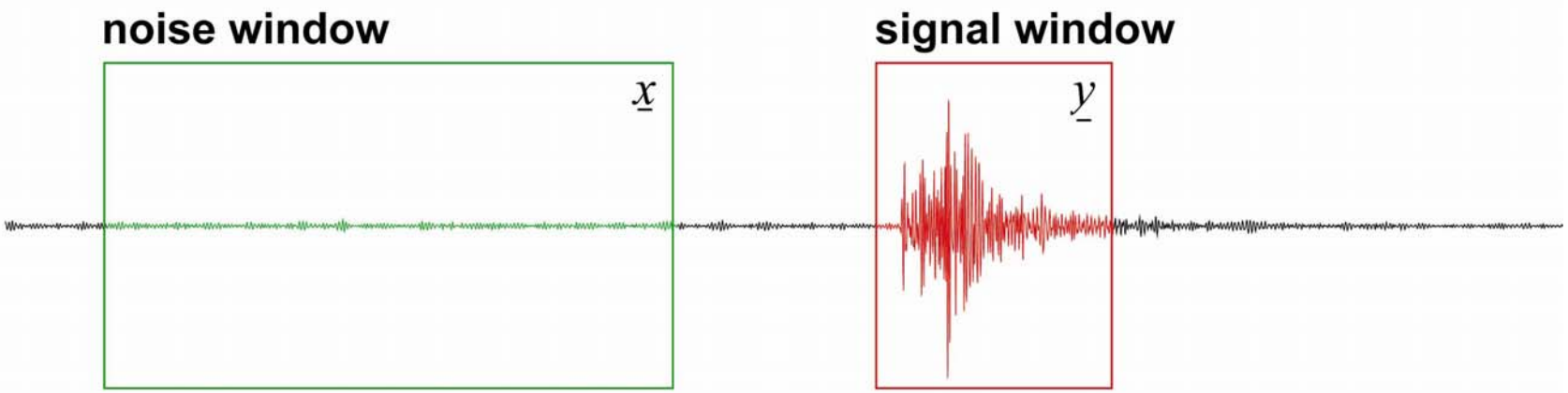
Signal Unknown	Knowledge of the Signal	Signal Known
Simple Energy Detectors (STA/LTA)	Subspace Detectors	Correlators (Matched Filters)

- Correlation detectors are very sensitive
- Energy detectors are broadly applicable
- An intermediate option is desirable

Subspace detectors add an uncertain signal model to the usual formulation of the detection problem



A single detection framework can span detectors ranging from simple energy detectors to correlators



detection rule

$$\frac{\underline{y}_p^T \underline{y}_p}{\underline{x}^T \underline{x} + \underline{y}^T \underline{y} - \underline{y}_p^T \underline{y}_p} \gtrless \text{threshold}$$

$$\underline{y}_p = \underline{U}\,\underline{U}^T \underline{y}$$

→

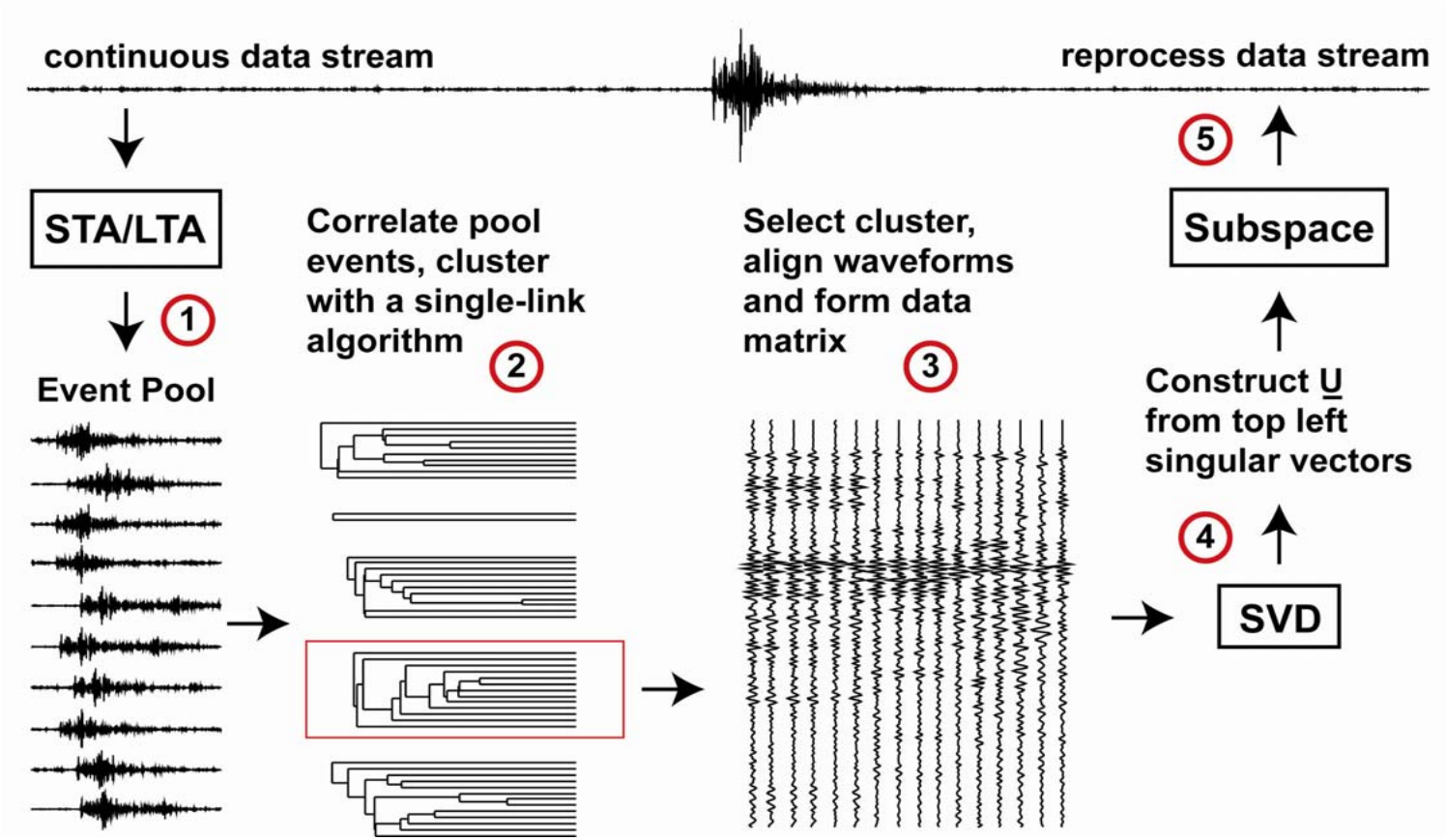
energy detector

$$\underline{U} = \underline{I} \qquad z = \frac{\underline{y}^T \underline{y}}{\underline{x}^T \underline{x}}$$

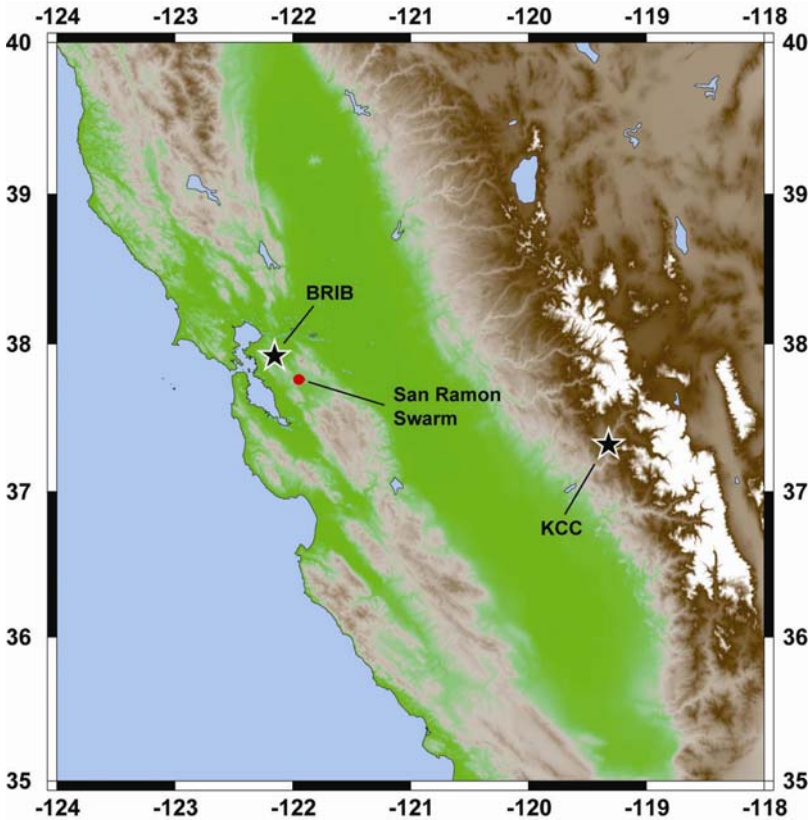
subspace detector

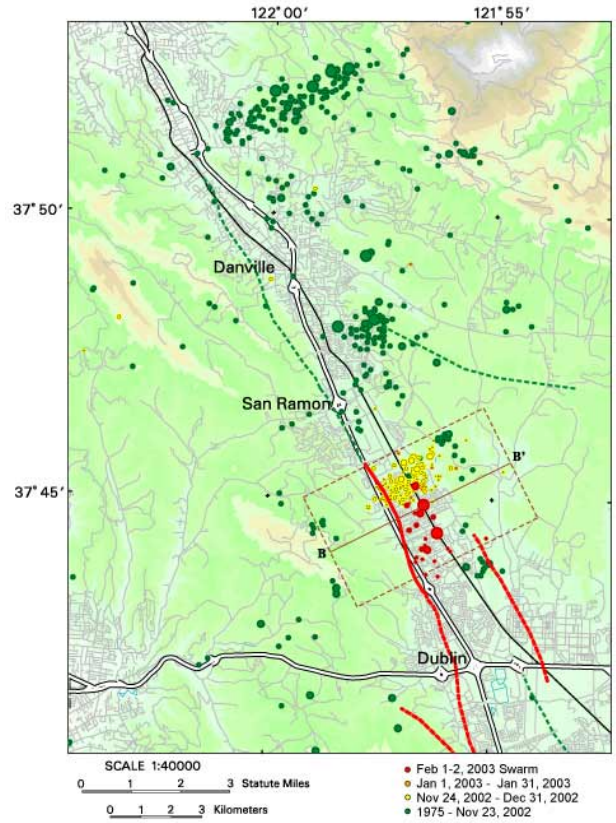
$$\underline{x}^T \underline{x} \rightarrow 0 \qquad z = \frac{\underline{y}_p^T \underline{y}_p}{\underline{y}^T \underline{y}}$$

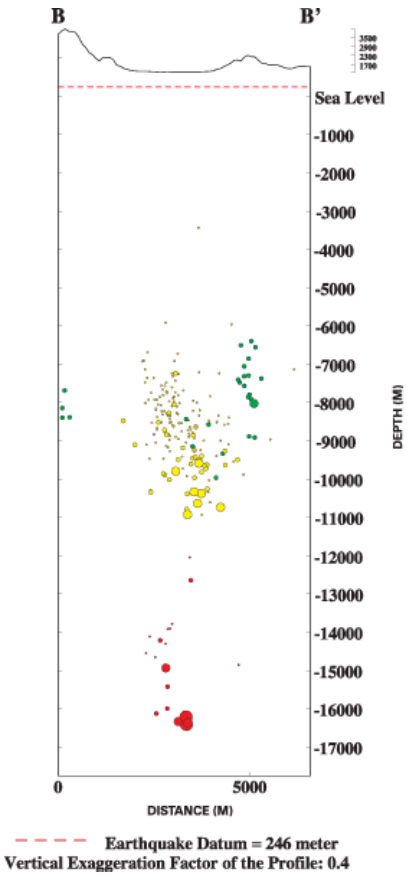
Processing sequence for detecting swarm events



Example: Nov-Dec 2002 San Ramon, California Swarm

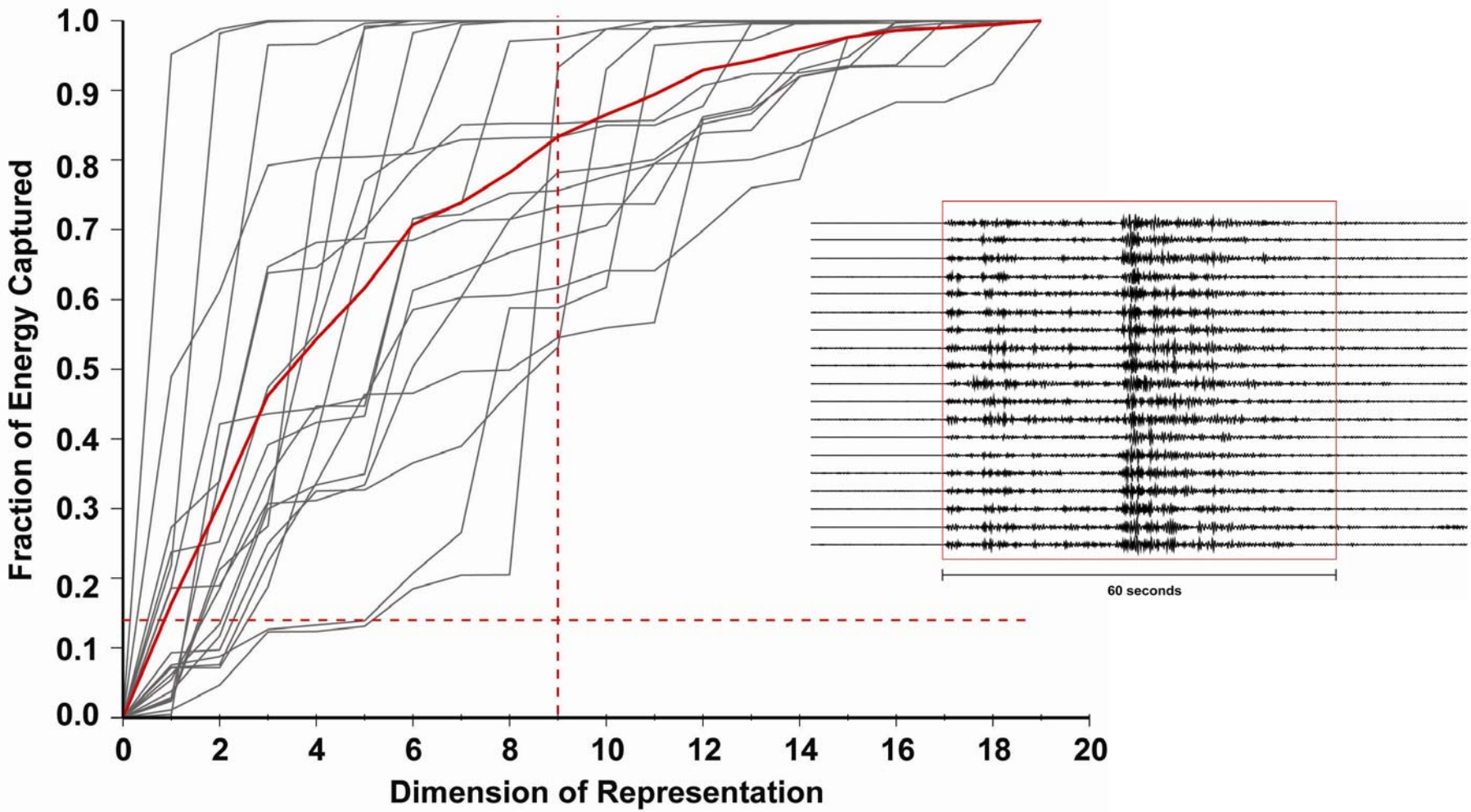






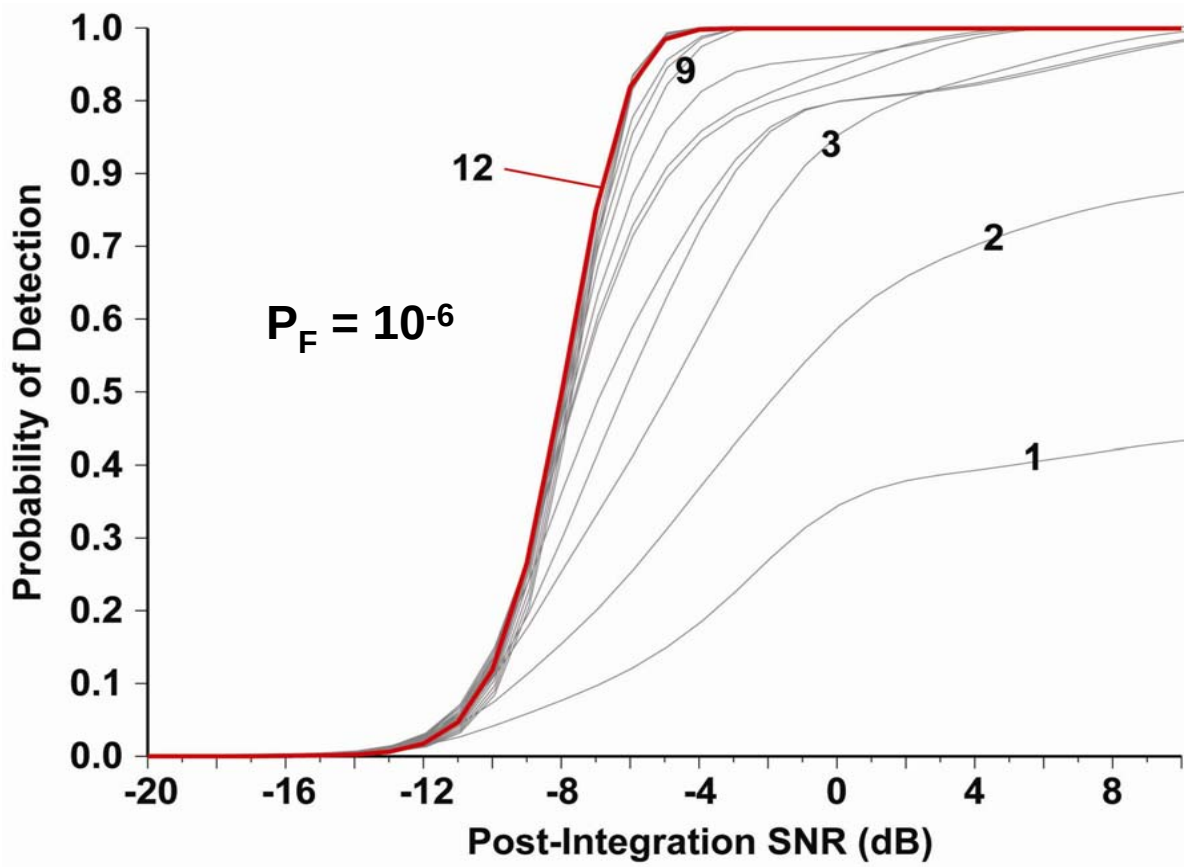
Data credit: NCEDC, Berkeley Seismological Laboratory

Detector dimension and threshold should be set to assure detection of the design events

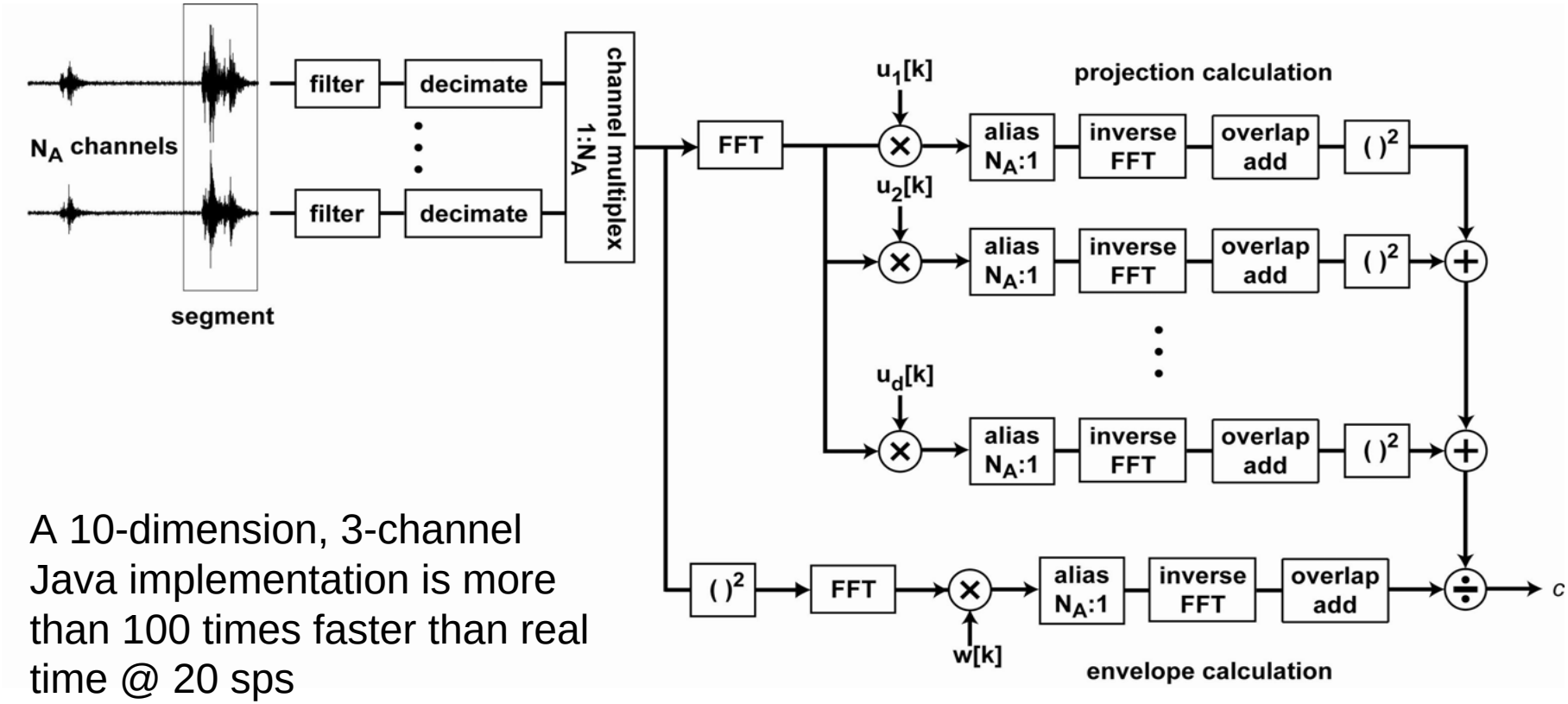


The subspace dimension is chosen to optimize the probability of detection

- Maximize P_D at a fixed P_F
- Minimize cost of computation where P_D is essentially constant

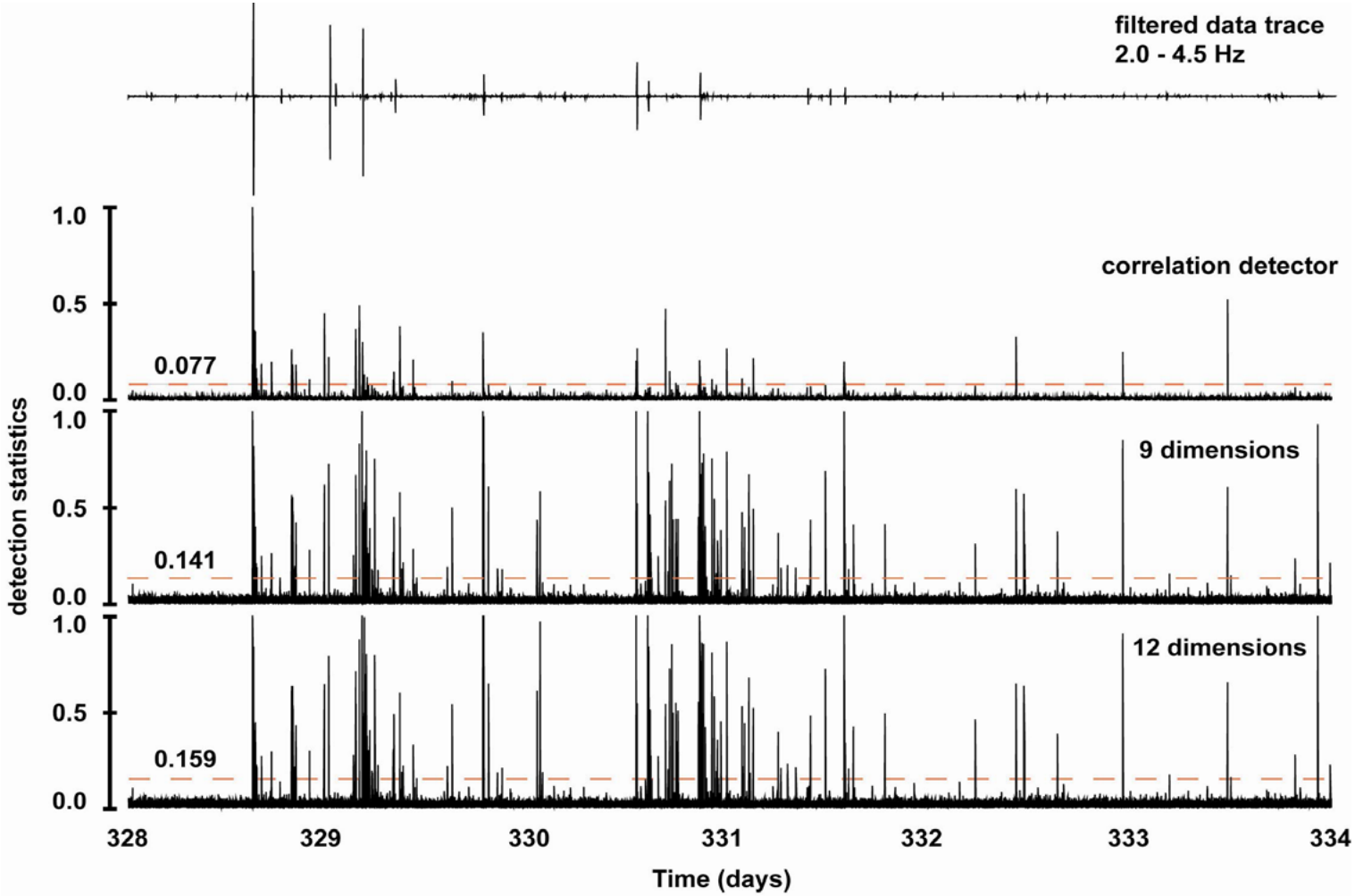


Subspace detectors have an efficient implementation

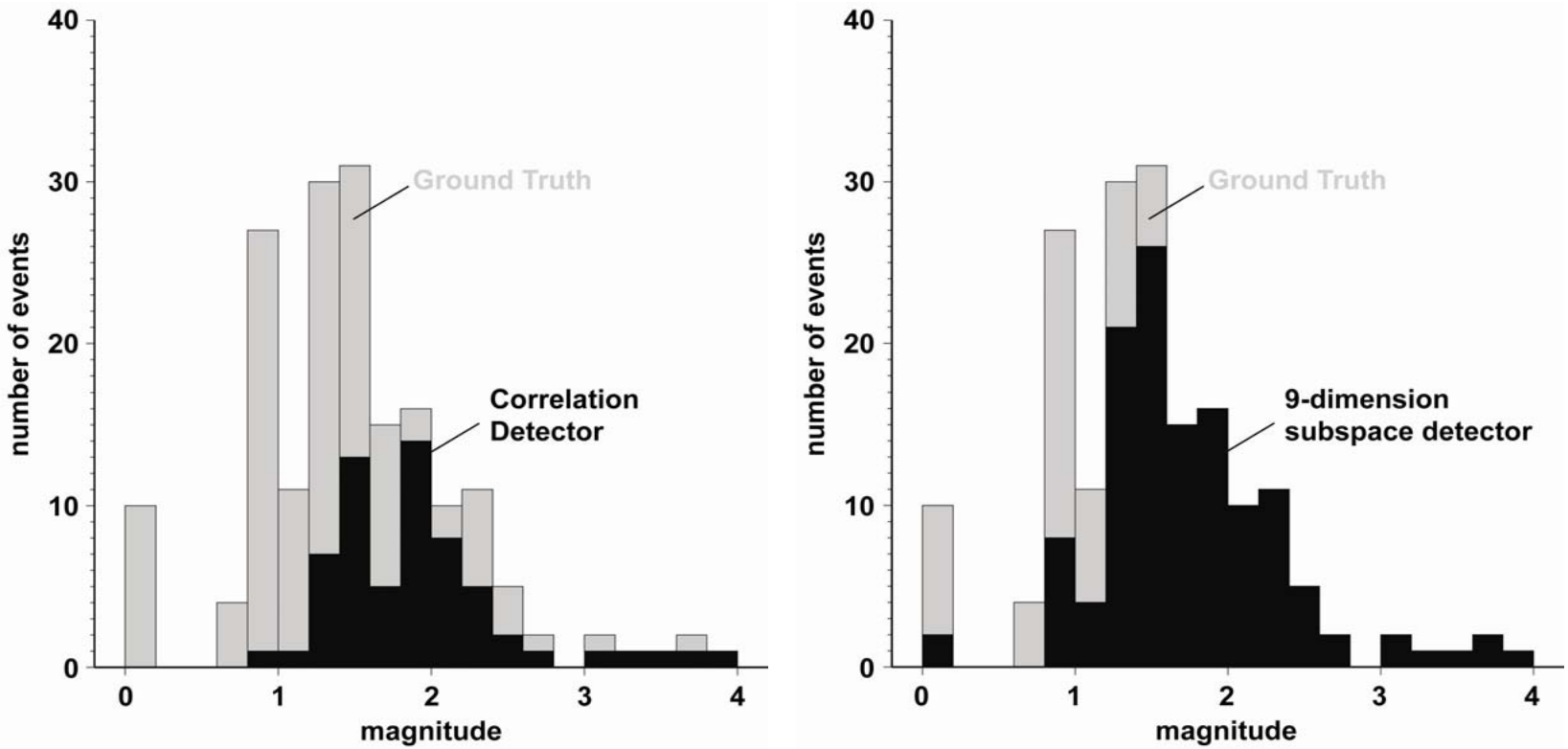


A 10-dimension, 3-channel Java implementation is more than 100 times faster than real time @ 20 sps

The subspace detector has a higher noise floor, but significantly better processing gain

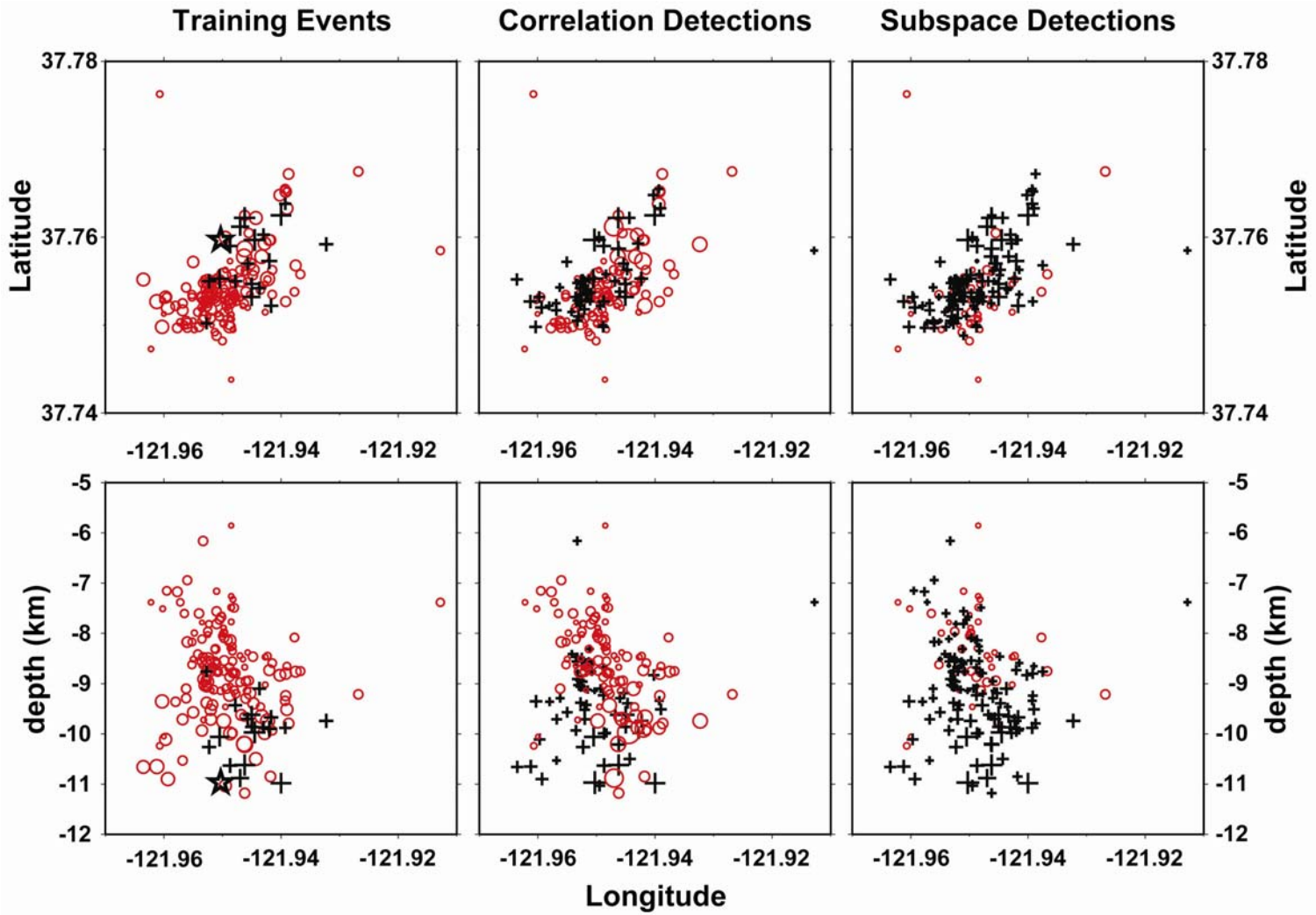


The subspace detector captures twice as many events as the correlator at the same theoretical P_F

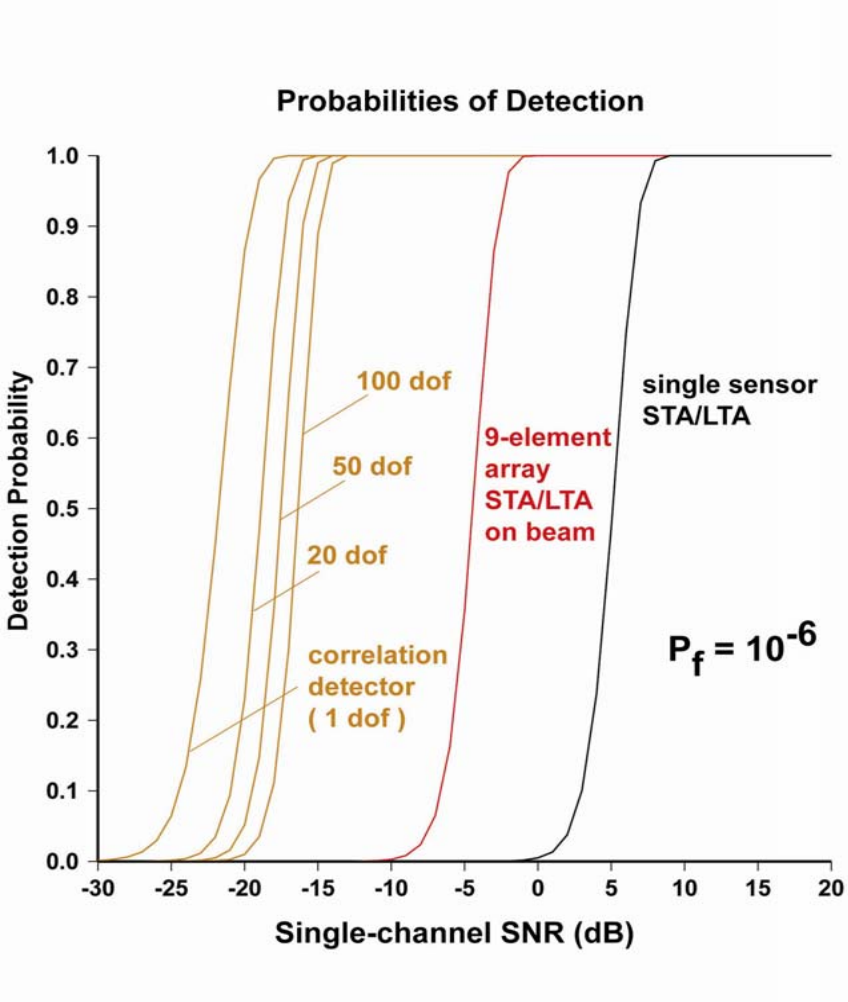


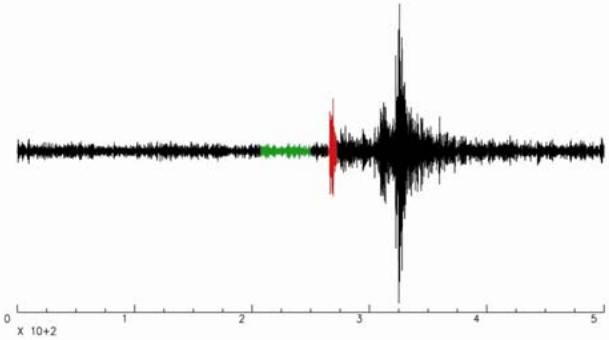
Detection threshold: ~1.5 @ 240 km

The subspace detector has broader coverage in the source region

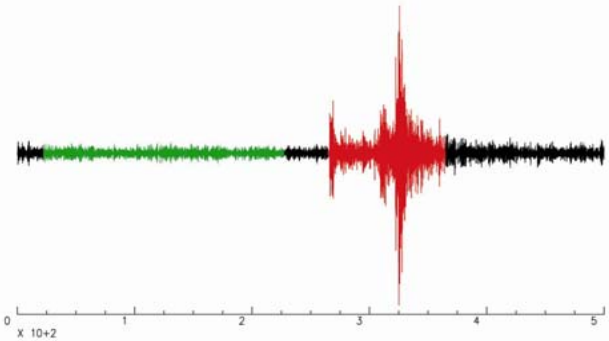


Under plausibly achievable circumstances, subspace detectors may provide as much gain as arrays





STA: 4 sec B: 2 Hz
LTA: 40 sec 9-channel beam



Correlation window: 100 sec
Noise window: 200 sec
B: 2 Hz
9 channels

Summary: subspace detectors are a promising approach to detecting uncertain seismic signals

- They allow systematic exploitation of partial information about the signal
- A rigorous statistical design approach is available
- There is the theoretical prospect of detectors “dialable” from simple energy detectors to correlators
- Good performance has been demonstrated on an earthquake swarm