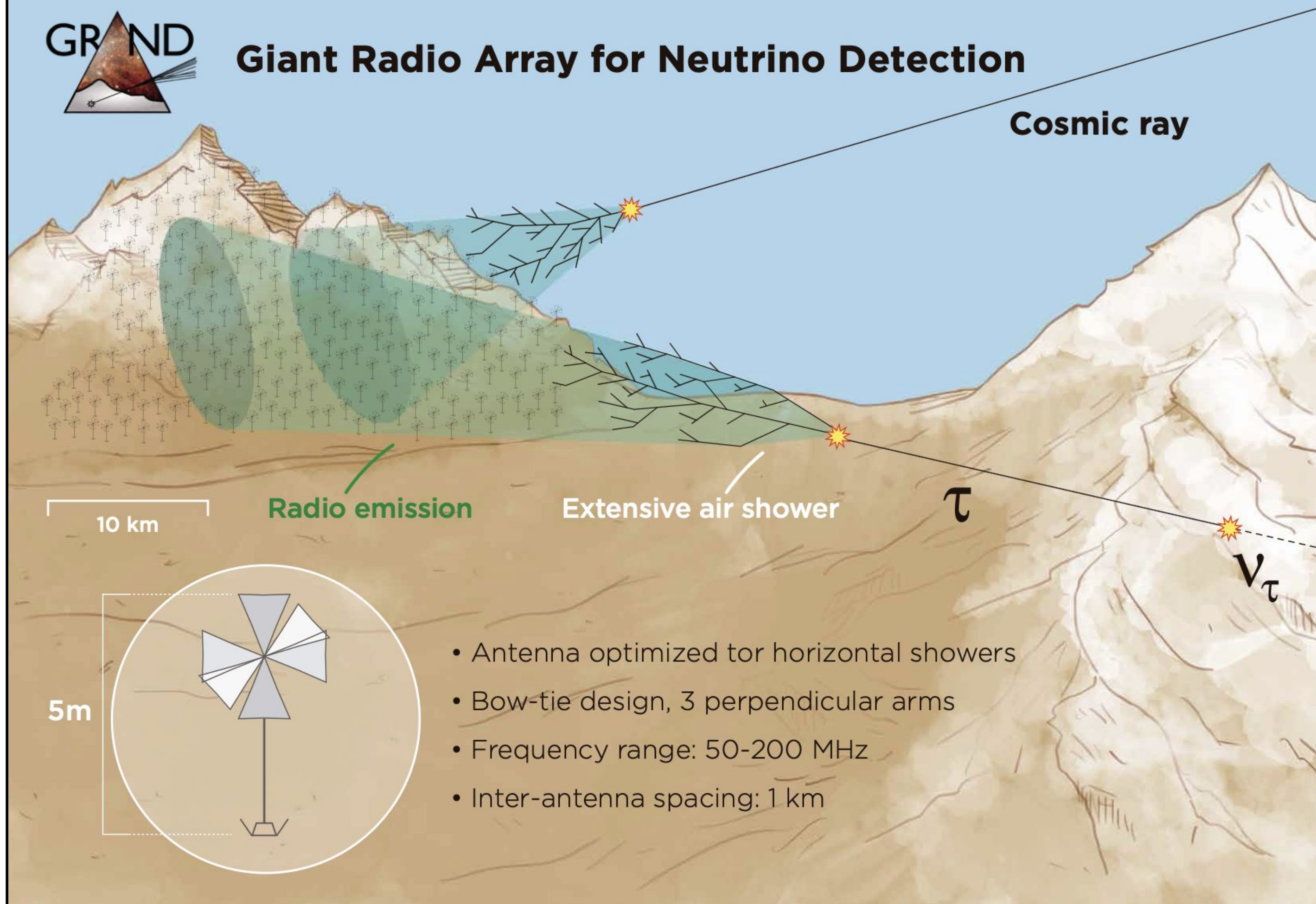
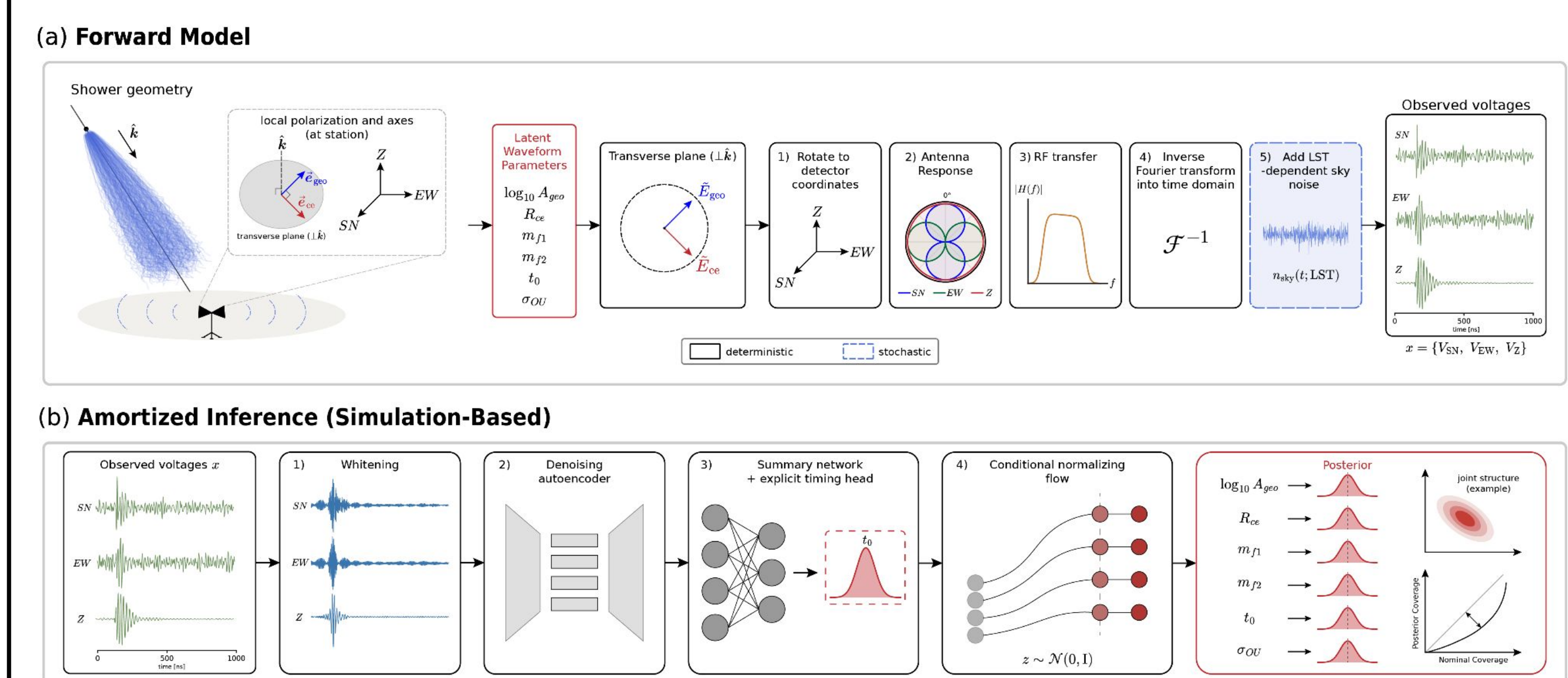


## Background



Design for Giant Radio Array for Neutrino Detection (GRAND), a planned radio array for the detection of ultra-high-energy cosmic rays, gamma rays, and neutrinos [Image credit: arXiv:1810.09994].

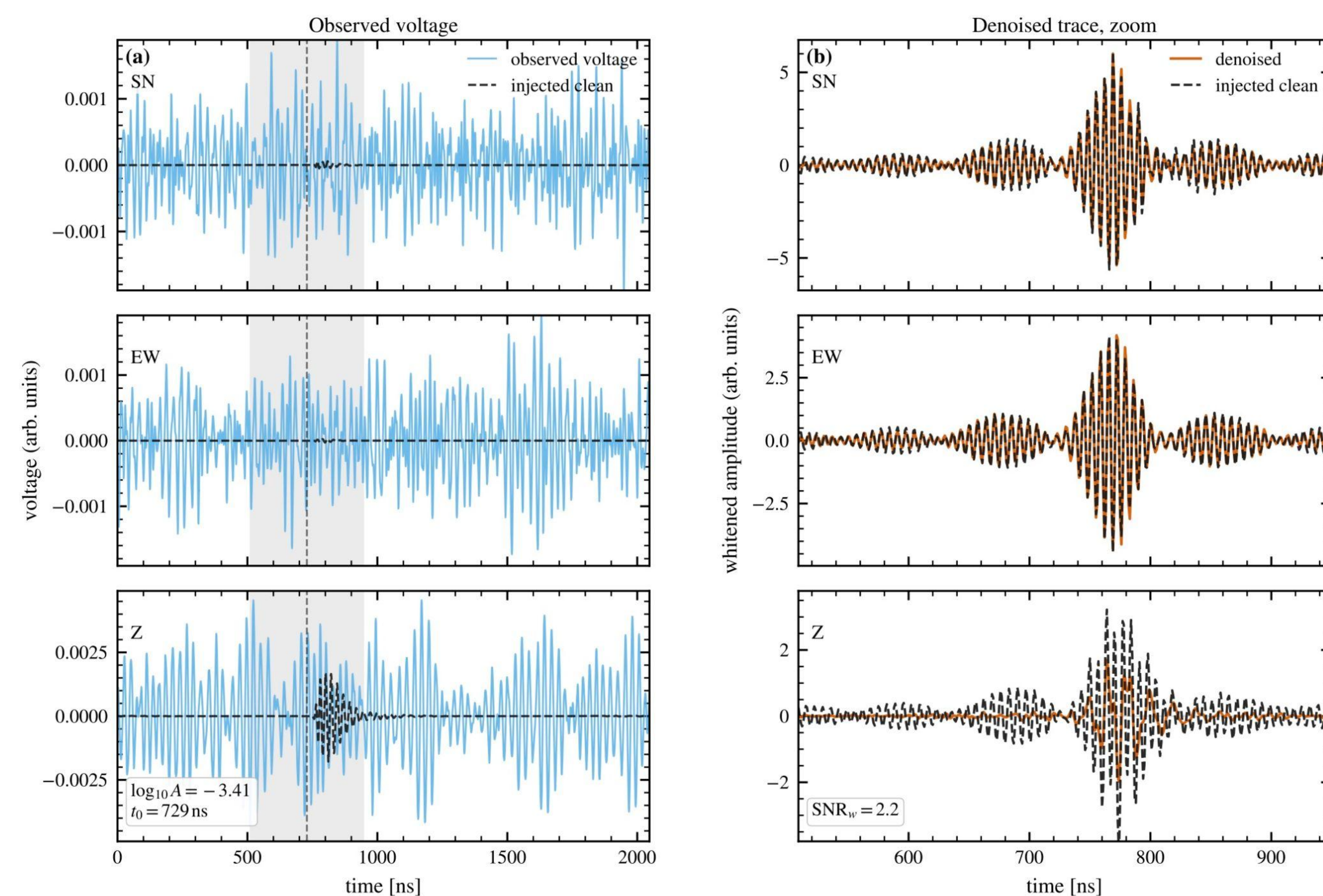
## SBI Pipeline



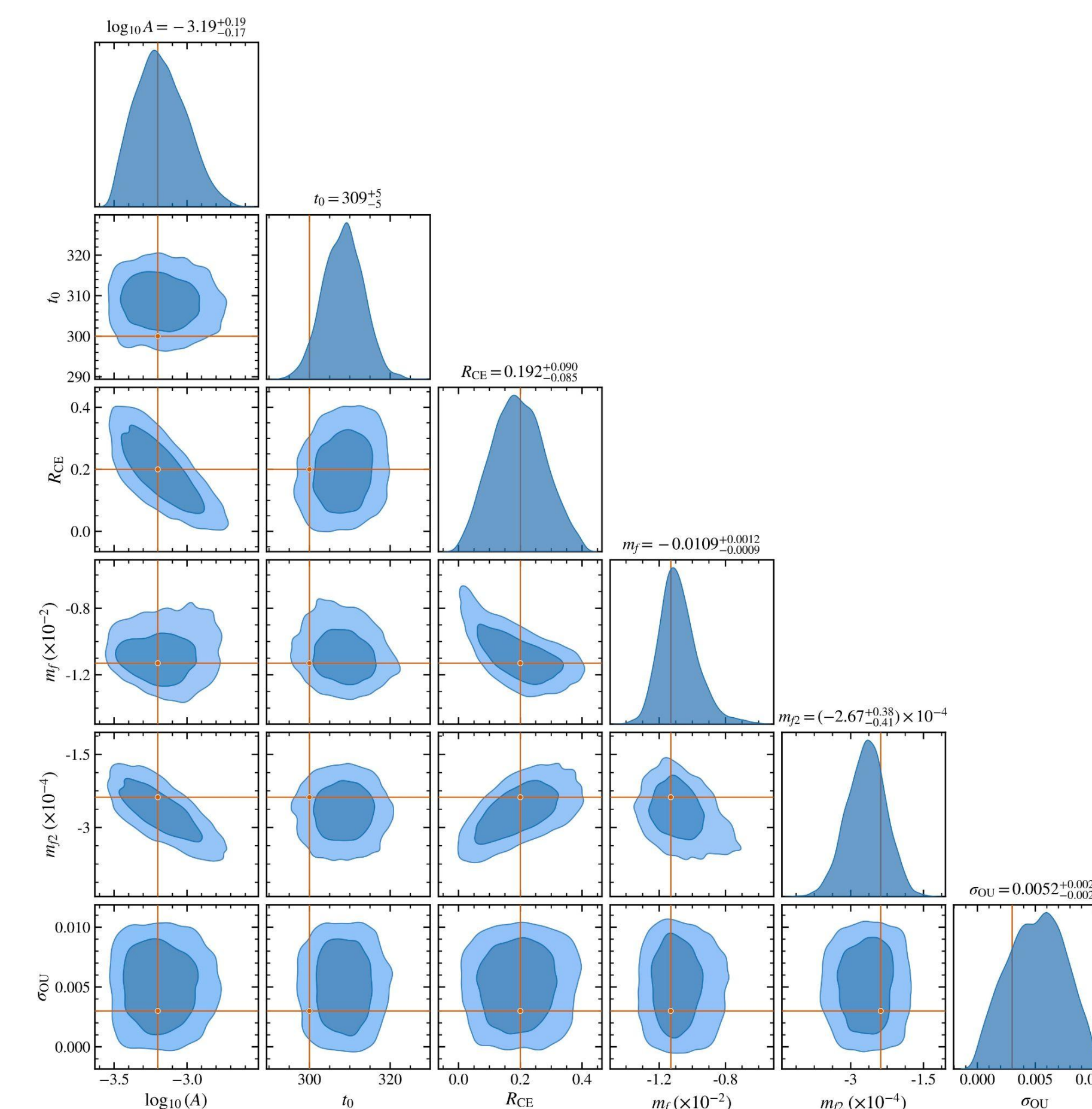
End-to-end reconstruction pipeline. The forward model creates realistic antenna observations of UHECR, gamma ray, and neutrino airshowers which are then whitened, denoised, and compressed and passed through a conditional normalizing flow to returns the desired posteriors.

- 6 waveform parameters:
  - Geomagnetic amplitude, charge-excess ratio, spectral slope, spectral curvature, pulse time, and smooth spectral modulation.
- Voltage trace is whitened in the 50-200 MHz.
- Summary network has 6.83 million trainable parameters compressed into a 192-dimensional output.
- The embedding appends summaries for amplitude and spectral shape, in addition to a time location channel.

## Amortized Inference



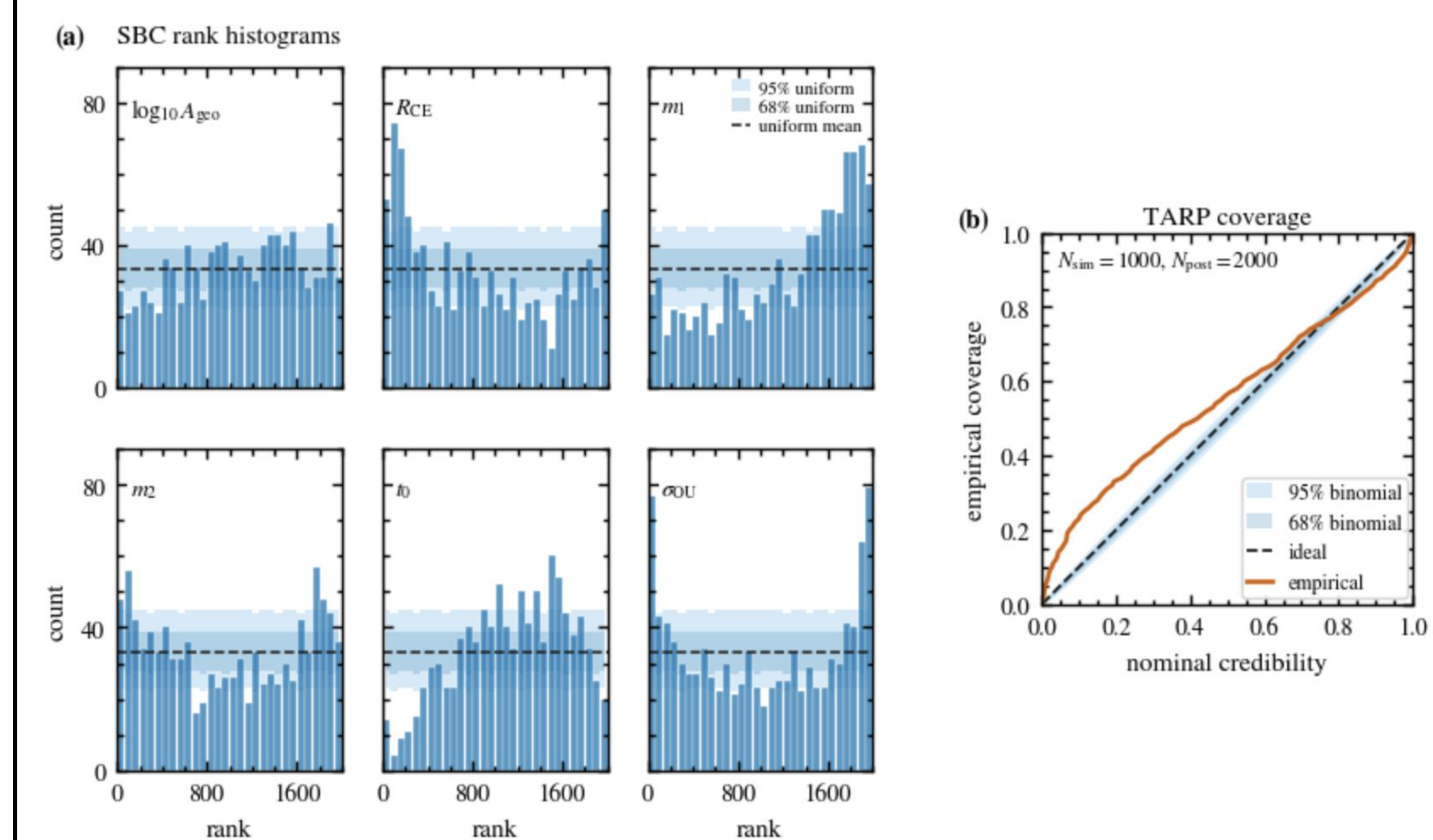
Example event showing the raw observed voltage, denoised waveform, and injected clean signal in the SN, EW, and Z channels.



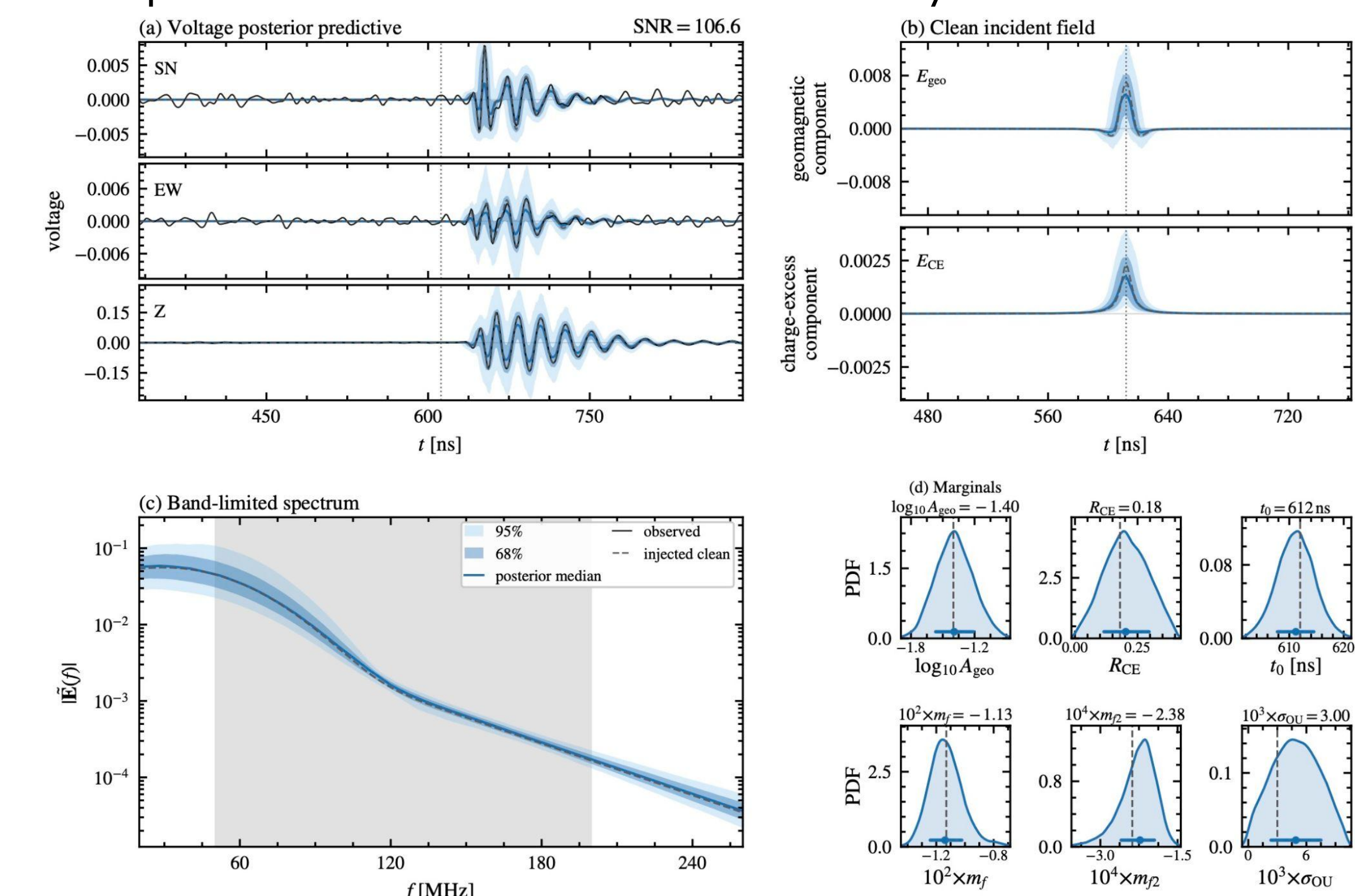
Representative six-parameter posterior for a simulated event

- Conditional normalizing flow learns to reconstruct posteriors for all parameters from the summaries.
  - 6 transforms and 80 hidden features.
- Model has learned non-trivial structure in the data, but not yet fully calibrated
  - TARP is OK, but SBC histograms for individual parameters not yet uniform.
- Amortized simulation-based inference can reconstruct waveform-level electric field parameters from noisy detector voltages.

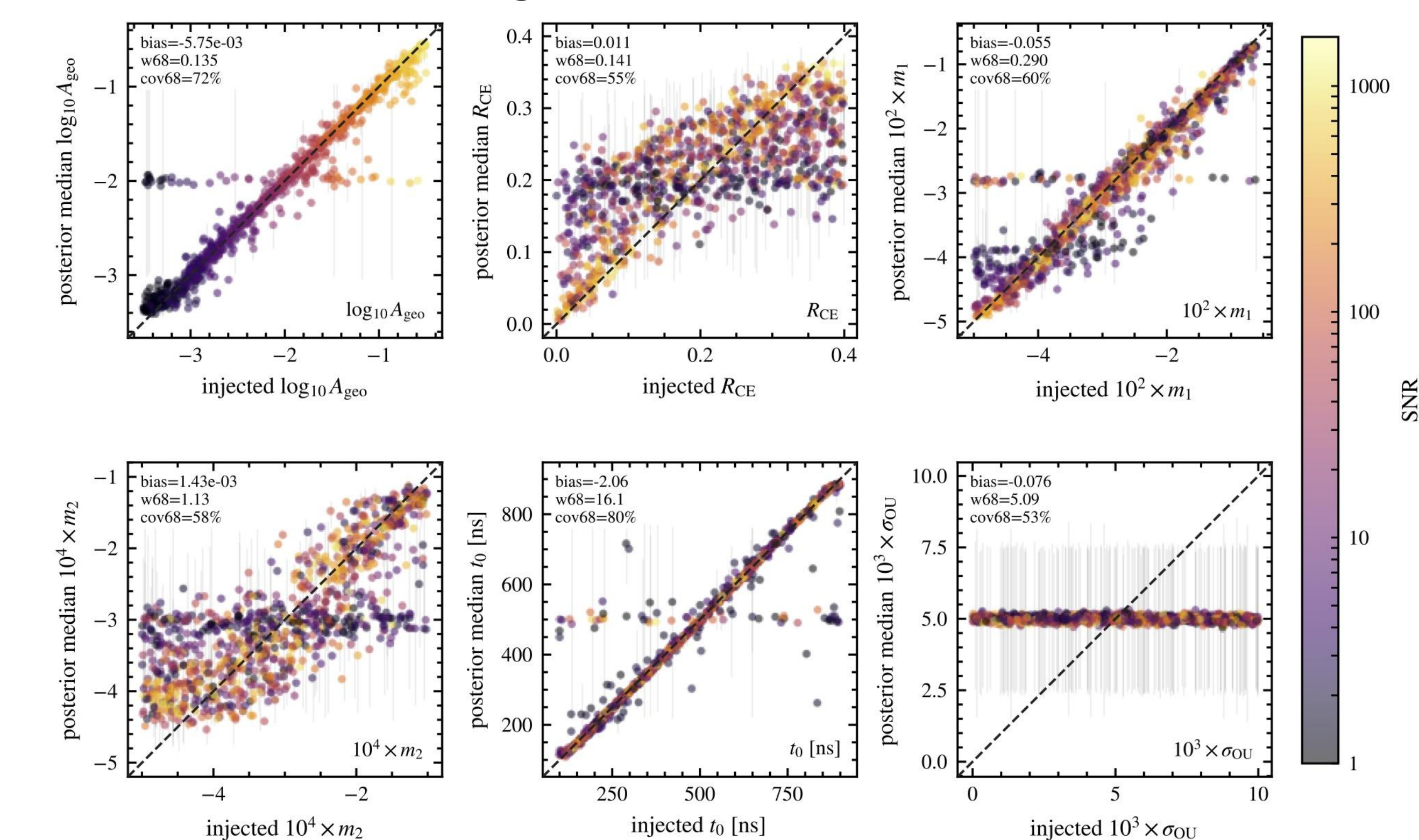
## Results



Calibration diagnostics. SBC rank histograms and TARP coverage test whether posterior uncertainties are statistically reliable.



Event-level posterior-predictive reconstruction for a representative held-out event with a large SNR.



Recovery of six latent waveform parameters on held-out simulations.