Estimating Single-Channel Source Separation Masks

Relevance Vector Machine Classifiers vs. Pitch-Based Masking

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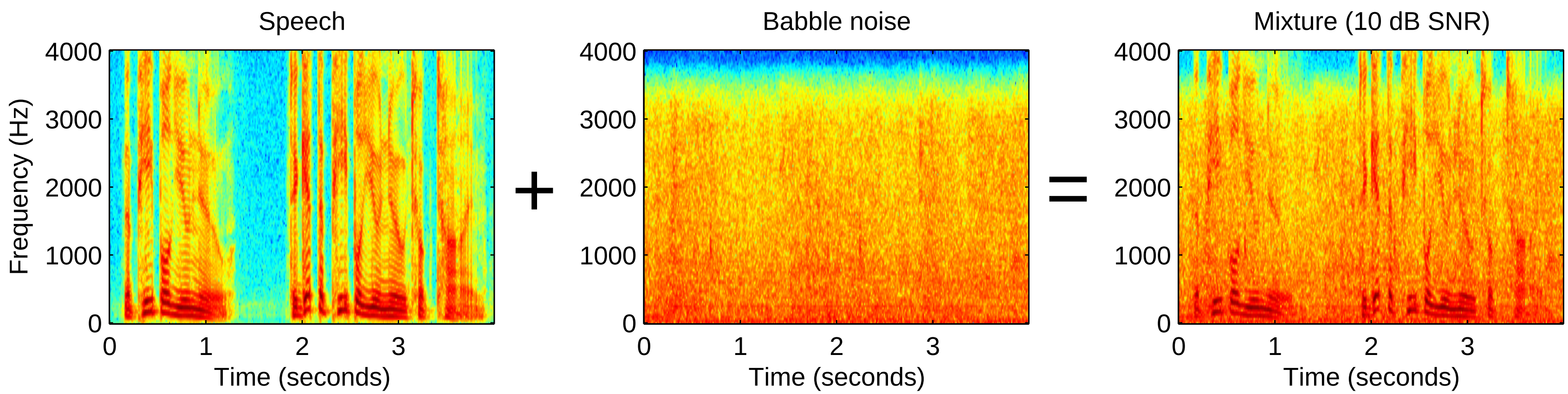
Single Channel Source Separation



- Given a monoaural signal composed of multiple sources
- e.g. multiple speakers, speech + music, speech + background noise
- Want to separate the constituent sources
- For noise robust speech recognition, hearing aids

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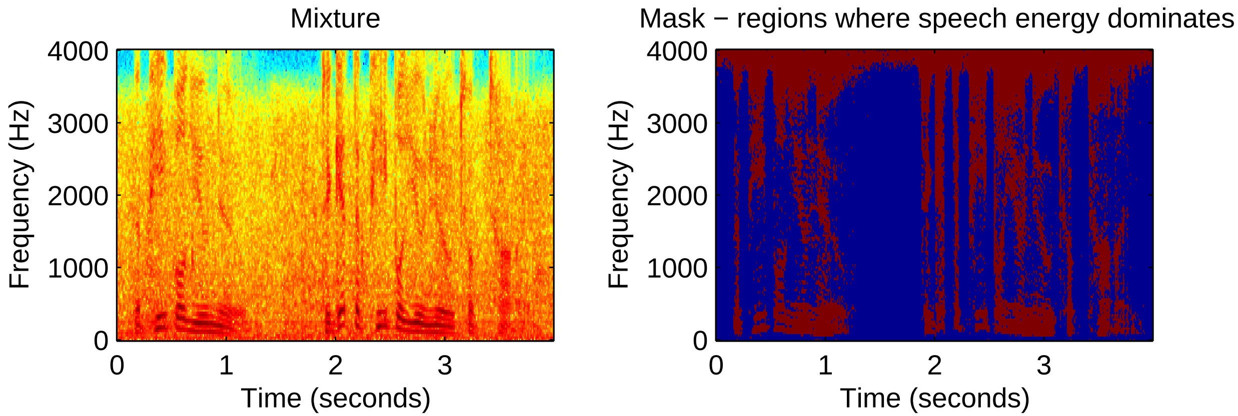
Missing Data Masks



- Leverage the sparsity of audio sources - only one source is likely to have a significant amount of energy in any given time-frequency cell
- If we can decide which cells are dominated by the source of interest (i.e. has local SNR greater than some threshold), we can filter out noise dominated cells ("refiltering" [3])
- Create a binary mask that labels each cell of the spectrogram as missing or reliable

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Mask Estimation As Classification [4]

- Goal is to classify each spectrogram cell as being reliable (dominated by speech signal) or not
- Separate classifier for each frequency band
- Train on speech mixed with a variety of different noise signals (babble noise, white noise, speech shaped noise, etc...) at a variety of different levels (-5 to 10 dB SNR)
- Features: raw spectrogram frames
  - current frame + previous 5 frames (~ 40 ms) of context

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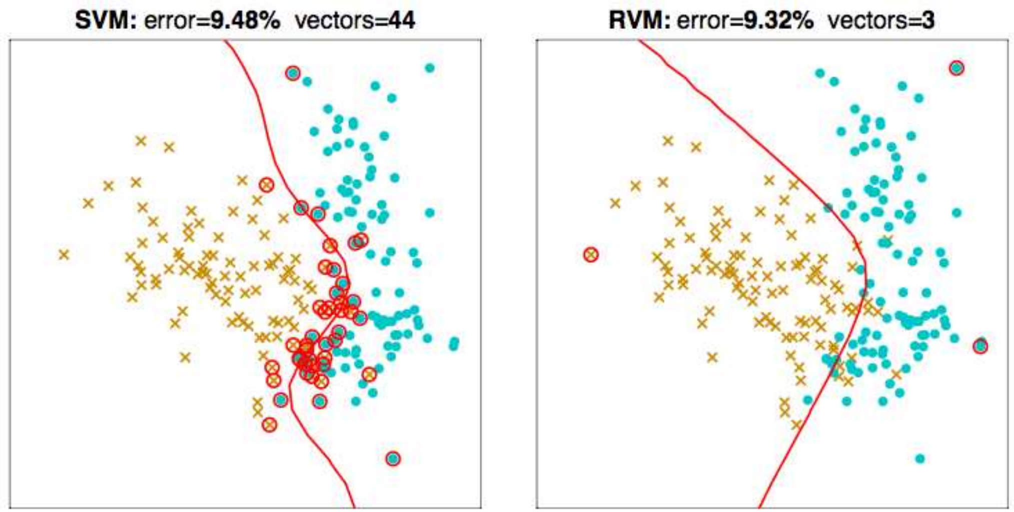
The Relevance Vector Machine [5]



- Bayesian treatment of the SVM
- Kernel classifier of the form:

$$y(\mathbf{z}|\mathbf{w},\mathbf{v}) = \sum_n w_n K(\mathbf{z},\mathbf{v}_n) + w_0$$

  - $\mathbf{z}$ = data point to be classified
  - $\mathbf{v}_n$ = nth support vector
  - w_n = weight associated with the nth support vector

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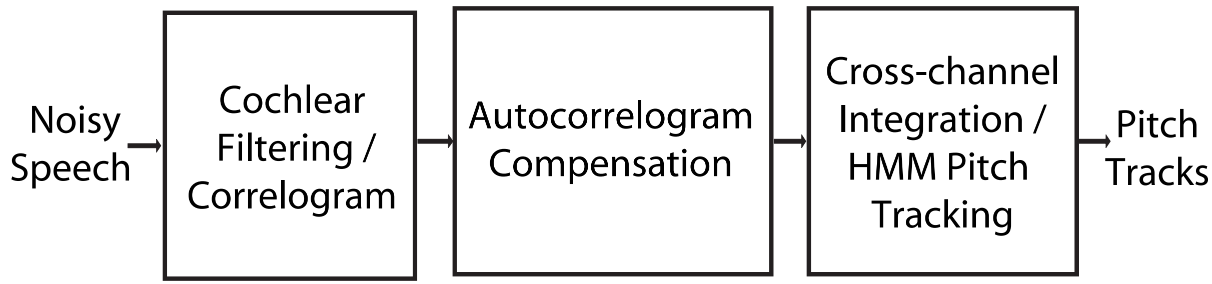
RVM Versus SVM

- Pros
  - Huge improvement in sparsity over SVM (~ 50 rvs vs. ~ 450 svs per classifier on this task) - faster classification
  - Wrap y in a sigmoid squashing function to estimate posterior probability of class membership.

$$P(t = 1|\mathbf{z}, \mathbf{w}, \mathbf{v}) = \frac{1}{1 + e^{-y(\mathbf{z}|\mathbf{w},\mathbf{v})}}$$

  - Masks are no longer strictly binary. Can use RVM to estimate the probability that each spectrogram cell is reliable.
- Cons
  - RVM training is significantly slower

CASA Pitch-based Masking [1]



- Most energy in speech signals is associated with the pseudo-periodic segments of vowel sounds
- Get envelopes of auditory filter outputs
- Find strong periodicities in short-time autocorrelation of each envelope
- Sum each channel to find single dominant periodicity
- Channels whose autocorrelation indicated energy at this period are added to the target mask

Missing Data Reconstruction [2]

- What if a significant part of the signal is missing?
- Want to fill in the blanks in spectrogram of mixed signal
- Do MMSE reconstruction on missing dimensions using signal model of spectrogram frames - GMM trained on clean speech
- Marginalize over missing dimensions to do inference

$$P(z_d|k) = P(r_d)\mathcal{N}(z_d|\mu_{k,d}, \sigma_{k,d}) + (1 - P(r_d)) \int \mathcal{N}(z_d|\mu_{k,d}, \sigma_{k,d}) dz_d$$

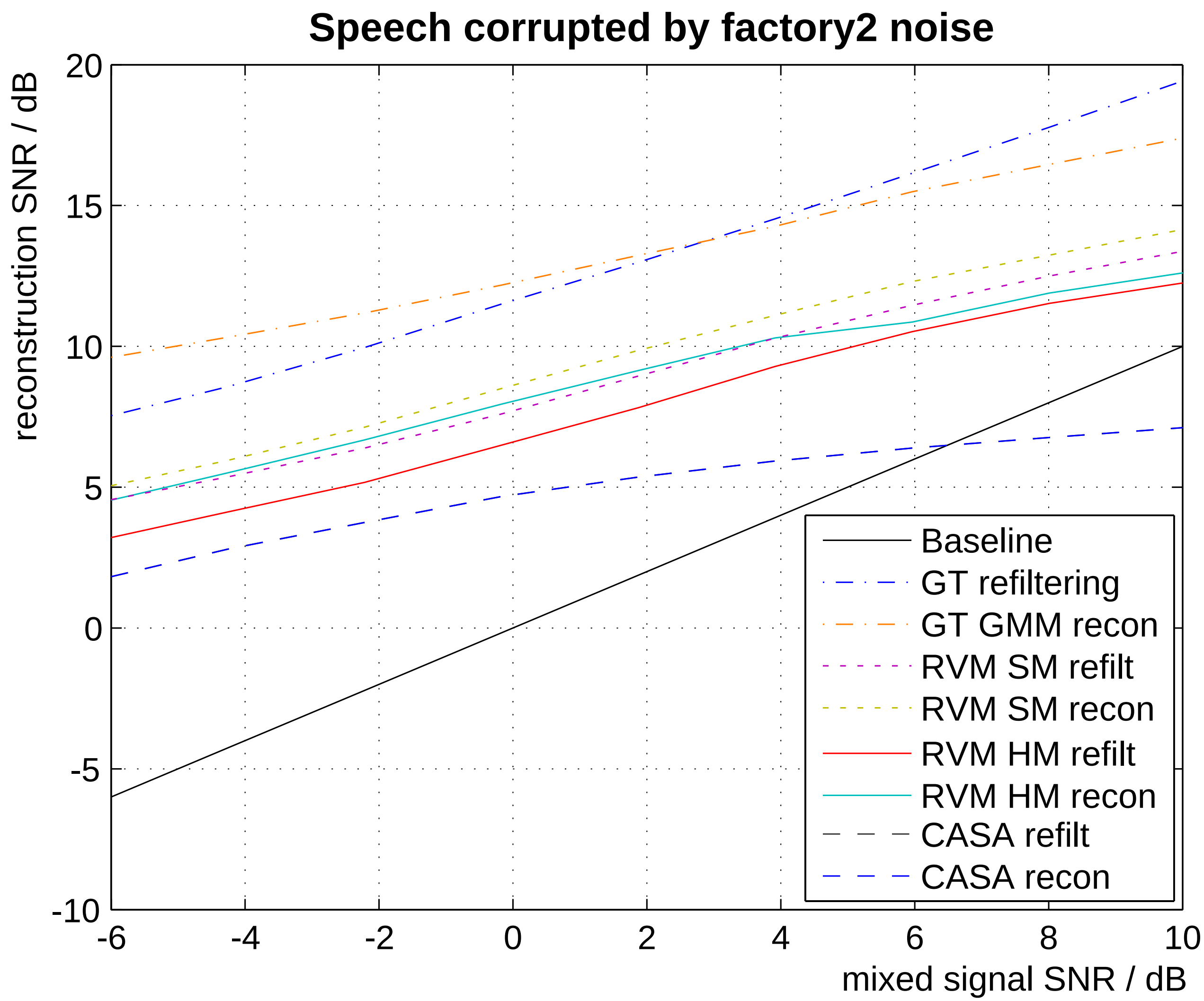
- MMSE estimator reconstructs by mixing the observed signal and GMM reconstruction based on the probability that each cell is reliable:

$$x_d = E[x_d|z] = P(r_d)z_d + (1 - P(r_d)) \sum_k P(k|z)\mu_{k,d}$$

Experiments

- Speech signal: single male speaker from audio book recording
- Training noise signals: Babble noise, speech shaped noise, factory noise 1
- Out of model noise signals used for testing: car noise, white noise, factory noise 2, music
- RVM trained on 20s of speech + noise
- 512 component GMM trained on 80s of clean speech

Experiments - Results



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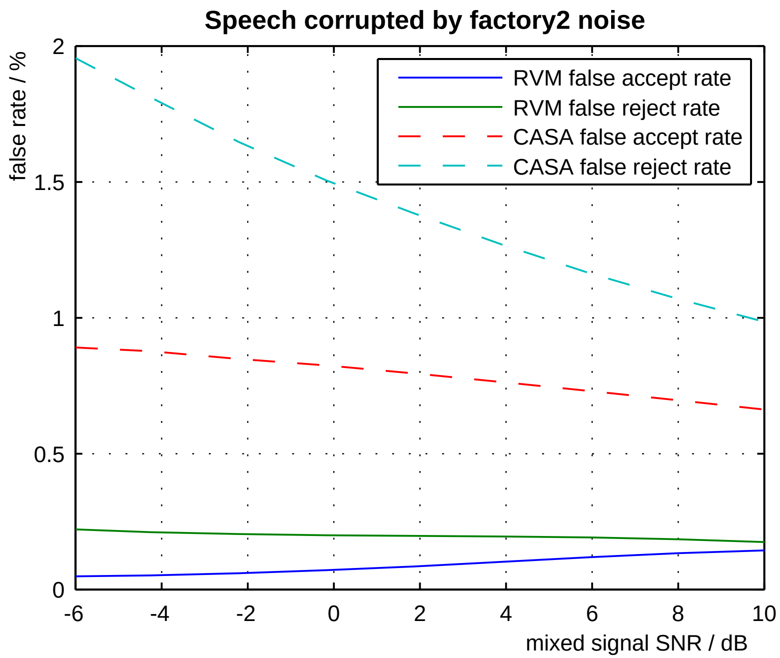
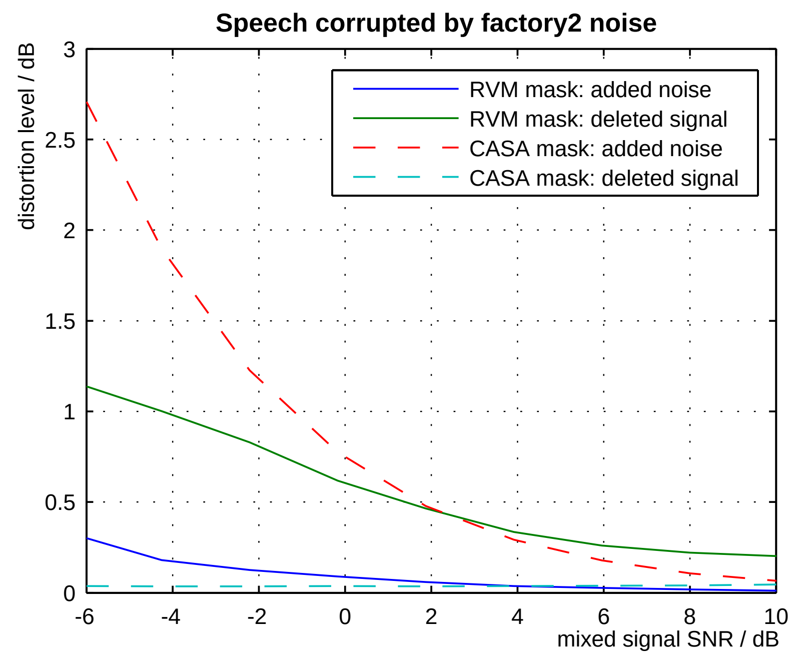
Experiments - Results

- GMM reconstruction outperforms simple refiltering since the GMM reconstruction can fill in the blanks
- Soft masks give about 1 dB improvement over hard masks
- CASA masks not as good as RVM masks
- Still room for improvement in mask estimation based on performance using ground truth masks

Experiments - Results





- False positive rate of CASA masks is much higher than that of RVM masks.
- Major problem with CASA mask is added noise. Deleted signal is not very significant in terms of signal energy
- RVM mask deletes a significant amount of signal energy

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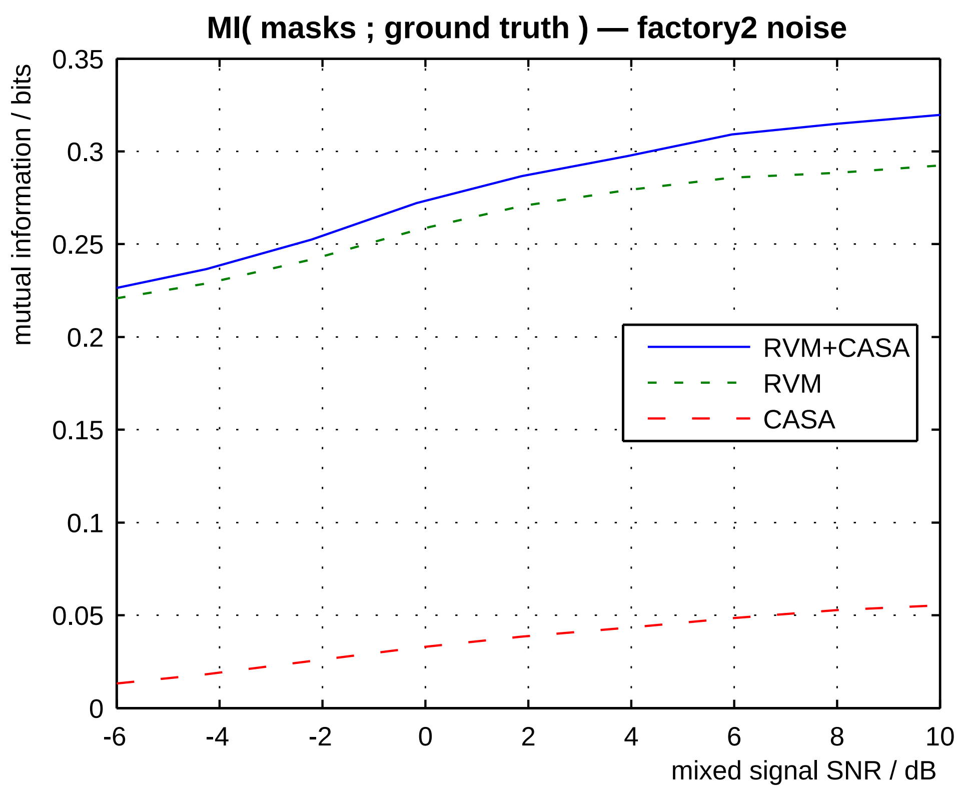
Experiments - Results



- RVM mask is significantly more informative about ground truth mask than CASA mask
- Some information in CASA mask is not captured by RVM mask

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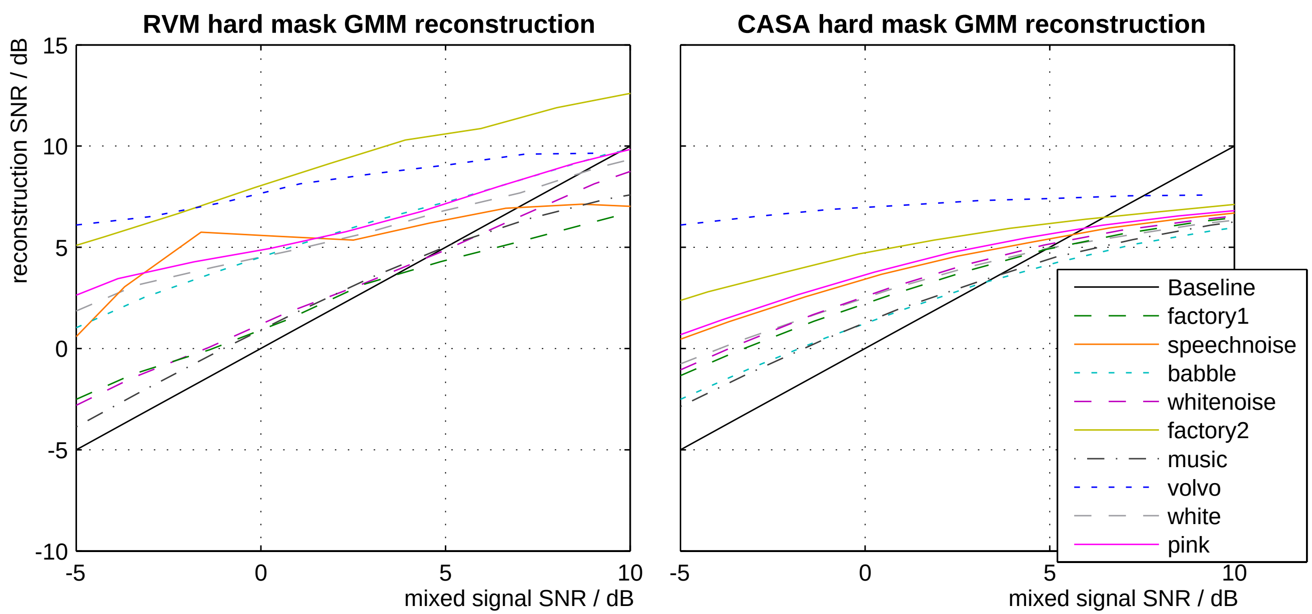
Experiments - Results



- Clear SNR boost when mixed signal at low SNR
- RVM clearly outperforms CASA system
- Both systems perform poorly on music noise
  - RVM not trained on highly pitched interference
  - CASA system can't distinguish between voiced speech and musical instrument harmonics

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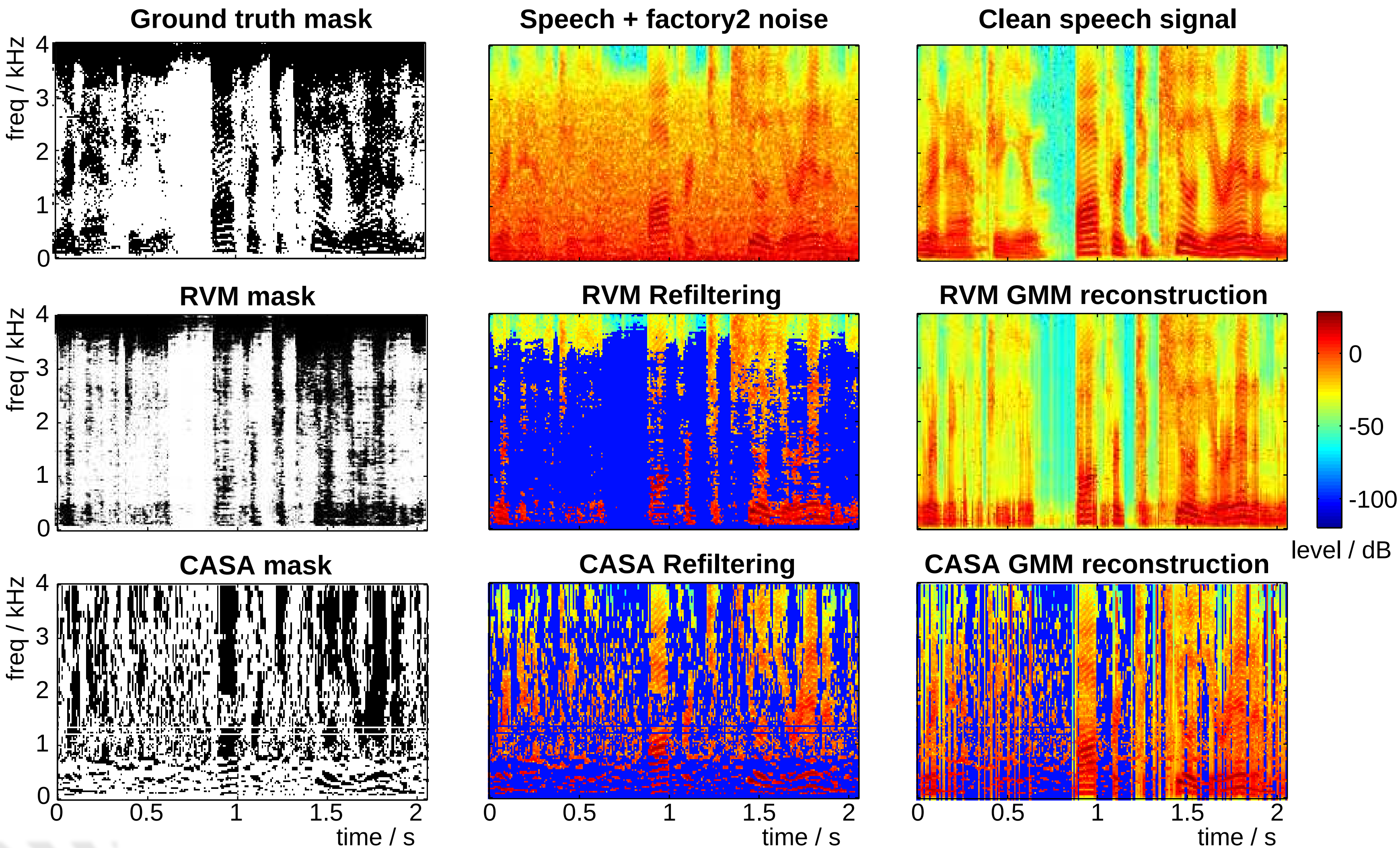
Spectrograms



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[2] B. Raj and R. Singh. Reconstructing spectral vectors with uncertain spectrographic masks for robust speech recognition. In *IEEE Workshop on Automatic Speech Recognition and Understanding*, pages 27–32, November 2005.

[3] S. T. Roweis. Factorial models and refiltering for speech separation and denoising. In *Proceedings of EuroSpeech*, 2003.

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[5] M. Tipping. The relevance vector machine. In S. A. Solla, T. K. Leen, and K.-R. Muller, editors, *Advances in Neural Information Processing Systems 12*, pages 652–658. MIT Press, 2000.