Devising Robustness Tests for Lunar-based Global 21-cm Experiments

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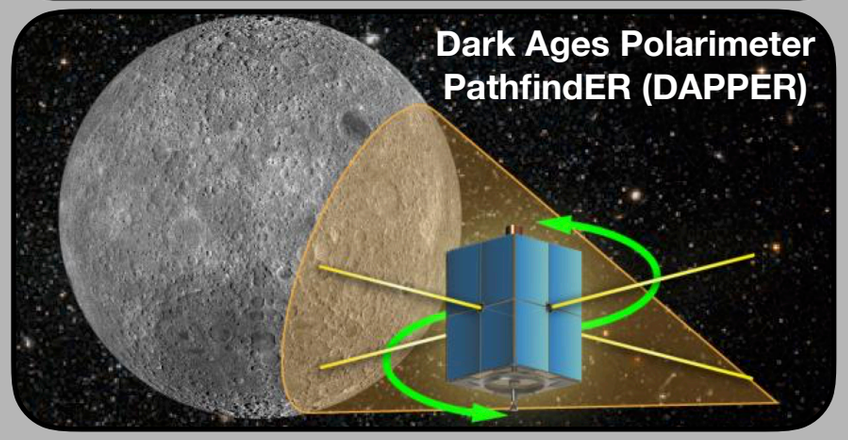
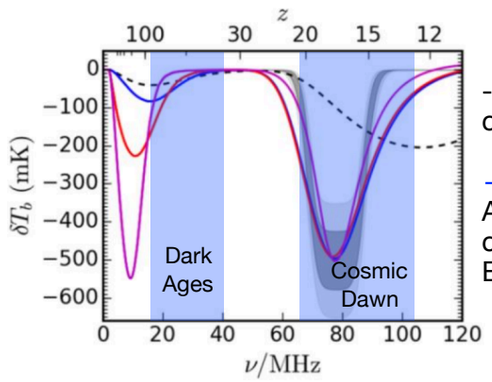
Cosmological observations from the farside



- **Objective 1:** Determine the level of (dis)agreement with the standard cosmological model in the Dark Ages.
- **Objective 2: A)** Determine the level of excess cooling above the adiabatic limit for Cosmic Dawn. **B)** Determine the properties of the first stars and black holes.

- DAPPER (link) is NASA-funded concept for lunar SmallSat to take low frequency observations during portion of orbit behind farside.
- Lunar farside offers pristine environment free of radio frequency interference (RFI) and contamination from Earth's ionosphere. Bassett et al. 2020 (link)
- 21-cm transition of neutral hydrogen provides probe of the early universe during Dark Ages and Cosmic Dawn.
- Dark Ages = period before stars "turned on."
- Cosmic Dawn = first stars, galaxies form.



- - Standard cosmological model

—/—/— Added cooling models consistent with EDGES detection

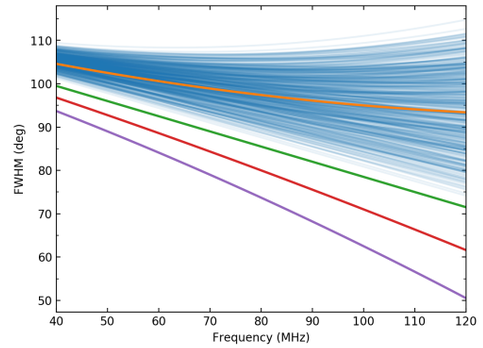
- DAPPER observes both Dark Ages and Cosmic Dawn.
- Will be able to differentiate between added cooling models consistent with EDGES and standard cosmology. Burns et al. 2020 (link)

Global 21-cm pipeline overview

Training sets created for each component of data → Singular Value Decomposition (SVD) on training set produces eigenmodes to fit data → Minimization of information criterion to determine number of modes to use in fit

See Tauscher et al. 2018 (link)

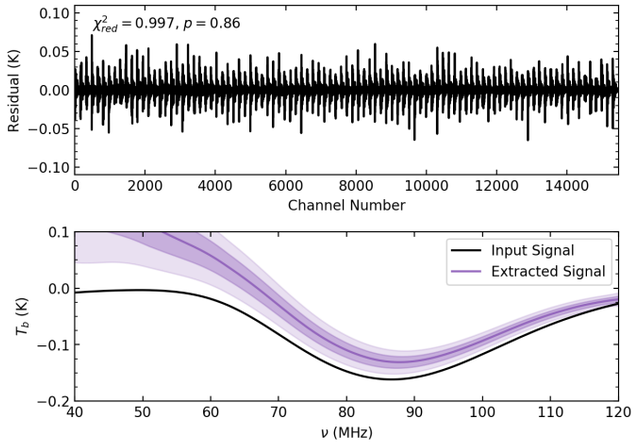
Pipeline analysis is only as good as our training sets. How do we have confidence that our training sets are sufficient to extract the 21-cm signal accurately?



Training set of beams is used to produce beam-weighted foreground SVD modes to fit the data.

What happens if we fit data using orange, green, red, and purple beams which are not included in the training set?

Example of fit to both foreground and 21-cm signal for data made with purple beam from above:



Chi-squared value indicates a good fit to the full data, but the signal extraction is flawed!

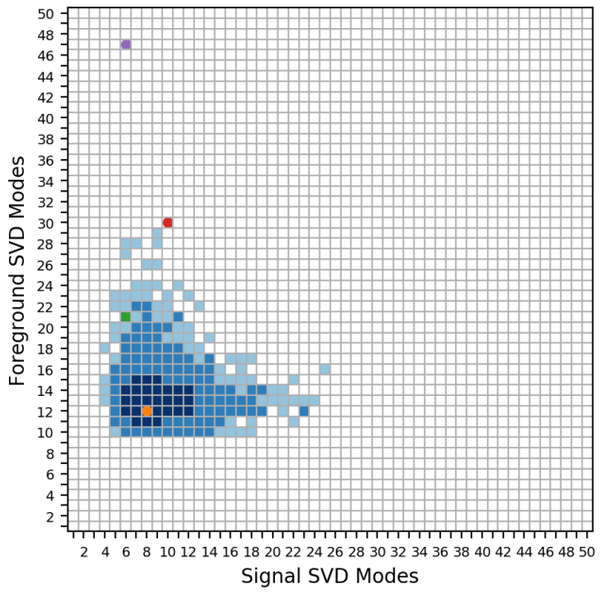
Chi-squared may not detect when something goes wrong when fitting multiple components simultaneously.

Ensuring robustness of 21-cm extraction

Need a way to assess the extraction of components that <u>does not rely on knowledge of their true form.</u>

Compare number of SVD modes for a fit to realizations made from training set curves

- Number of SVD modes for each component can be computed for any fit.
- If fit requires more SVD modes than training set realizations, training sets are likely different from data in some way.



Blue contours contain 68, 95, and 99.7 percent of 5000 fits made from training sets. Colors correspond to fits using beams from figure to the left.

Bassett *et al.* (in preparation)

- Orange and green beams not in training set, but number of modes chosen lies well within distribution due to similarity to training set curves.
- Red and purple beams require more modes, indicating training sets should be altered before analysis repeated.
- Fits require more foreground modes but not more signal modes, indicating foreground (rather than signal) training set is insufficient.

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