Ultra-precise radio interferometer simulation for 21cm Cosmology and Beyond

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Experiments aiming to detect the faint signature of a 21cm background against strong foregrounds must take radio instrumentation to new levels of precision. The requirement might be generalized to be a spectral line dynamic range of one part in 10,000; this is the accuracy to which the foreground continuum must be subtracted. At this level even a small amount of overfitting can lead to false positives or negatives. Standard scientific practice in cases like this is to test analysis on simulated data products, and even incorporate forward modeling into parameter estimation. Here, the interferometer presents a challenge: the forward model task is compute intensive. Most simulators make strong approximations in the interests of time, for example many allow non-uniform sky sampling to take advantage of the FFT algorithm. Developed in a research environment rather than a tool development framework, most of our simulation codes suffer from challenges to robustness. Low levels of test coverage and documentation coupled with sometimes arcane acceleration optimizations makes it difficult to diagnose issues at the precision needed. Finally, many codes are part of the pipeline under test, raising the spectre of unintentional experimenter bias. Thus we have been motivated to create a simulator, pyuvsim, which provides a community validation product suitable for comparison against data and fast simulators. The code calculates visibilities summing over a sky modeled as a sum over a densely sampled collection of gaussian sources. The calculation is optimized for speed where possible by vectorization of geometry calculations and has been developed from the ground up to be scaled out using Message Passing Interface. Testing and validation products are available at several levels. The visibility engine is covered by a variety of unit-tests for which there are analytic solutions including both point sources and diffuse flux. Larger reference simulations are provided as a comparison point to other codes. These are provided along with all instrument and sky parameters to allow an apples to apples comparison. Finally very large simulations have been generated to test for small effects spread across many data points. For more please visit pyuvsim.readthedocs.io