The Effect of Primary Beam Sidelobes on Delay and Fringe Rate Transforms

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ABSTRACT

This memo presents simple simulations to explore the possibility that spatially oscillatory beams (e.g. those with sidelobes) can introduce frequency structure (and, in the case of drift scanning instruments, temporal structure) which could *beat* with the interferometric fringes used as the basis of the delay and fringe rate transforms. A beat frequency could be larger than the maximum celestial delay or fringe rate set by the horizon limit and array geometry, so this effect could be worrisome for analyses that depend on power staying within these limits (or for the interpretation of aggressive delay or fringe rate filtered data). Using simple simulations, I find no evidence for this effect at an appreciable level, but further study may still be warranted when more detailed instrument simulations are performed.

1. Beam and Instrument Models

I simulate the visibilities for one 14 m east/west baseline over 24 hours. I use three different models for the primary beams of the elements: a flat response, a gaussian beam, and an airy disk beam. The latter two models assume a dish diameter of 14 m, have linear frequency dependence in their widths, and are shown in Figure 1.

2. Simulations

Figure 2 shows the simulated visibilities over 24 hours for an array located in Green Bank, WV. Data are simulated over a band from 100 to 200 MHz with 1024 spectral channels. Integrations in time are 10 seconds. The sky model consists of two points sources: Cygnus A (which transits near zenith) and Cassiopeia A (which never sets). The drift tracks for the two sources are illustrated with black lines in Figure 1.

Figure 3 shows the delay spectra of each simulation. The colorscale spans six orders of magnitude.

Figure 4 shows the fringe rate transform of each simulation. The colorscale again spans six orders of magnitude.

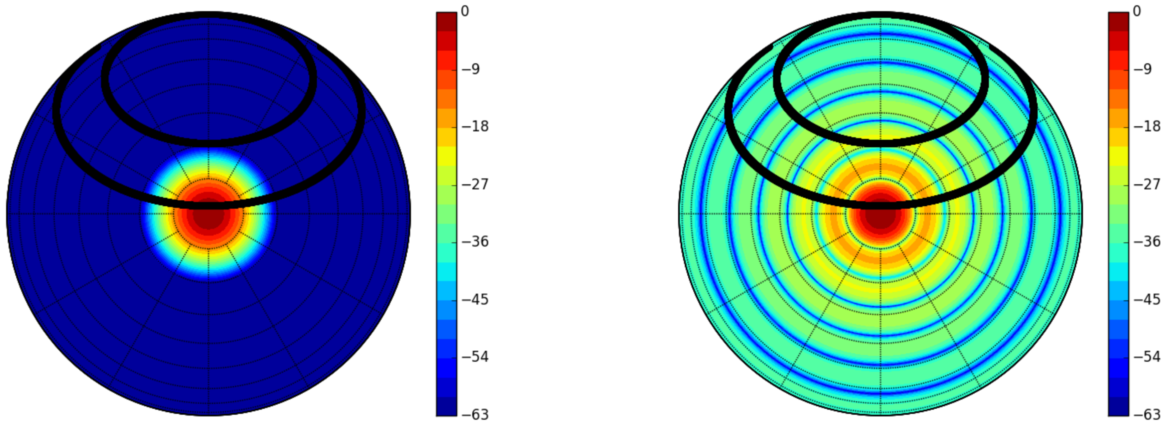

Fig. 1.— *Left*: The gaussian beam model. *Right*: The airy disk beam model. Color scales are in dB; each color gradation corresponds to 3 dB. Black lines corresponds to the tracks of Cygnus A and Cassiopeia A for an array located at Green Bank, WV. Both models are plotted at 150 MHz.

3. Conclusions

While the delay space behavior does not appear to be significantly affected by the presence of beam sidelobes, the fringe rate space transforms do appear quite different. However, this structure also seems to appear in the flat beam simulation, suggesting that the extra power comes from another source than a beating with the beam sidelobes. This is largely confirmed by looking at the fringe rate transforms of simulations including only Cassiopeia A (Figure 5).

This result suggests that the additional structure in fringe rate space comes from the sharp feature introduced by the setting of Cygnus A. This sharp feature is effectively missing from the Gaussian simulation, which smoothely goes to zero response at the horizon. The airy disk beam, however, has non-zero response at the horizon and sees this effect as well. Cassiopeia A never sets, however, and so also does not introduce a sharp feature in time.

These simulations are clearly cursory and cannot be the final word on this matter. However, in this quick analysis, there appears little evidence that the presence of oscillatory spatial structure in the beam “beats” with the interferometric fringes and creates supra-horizon power in any appreciable way.

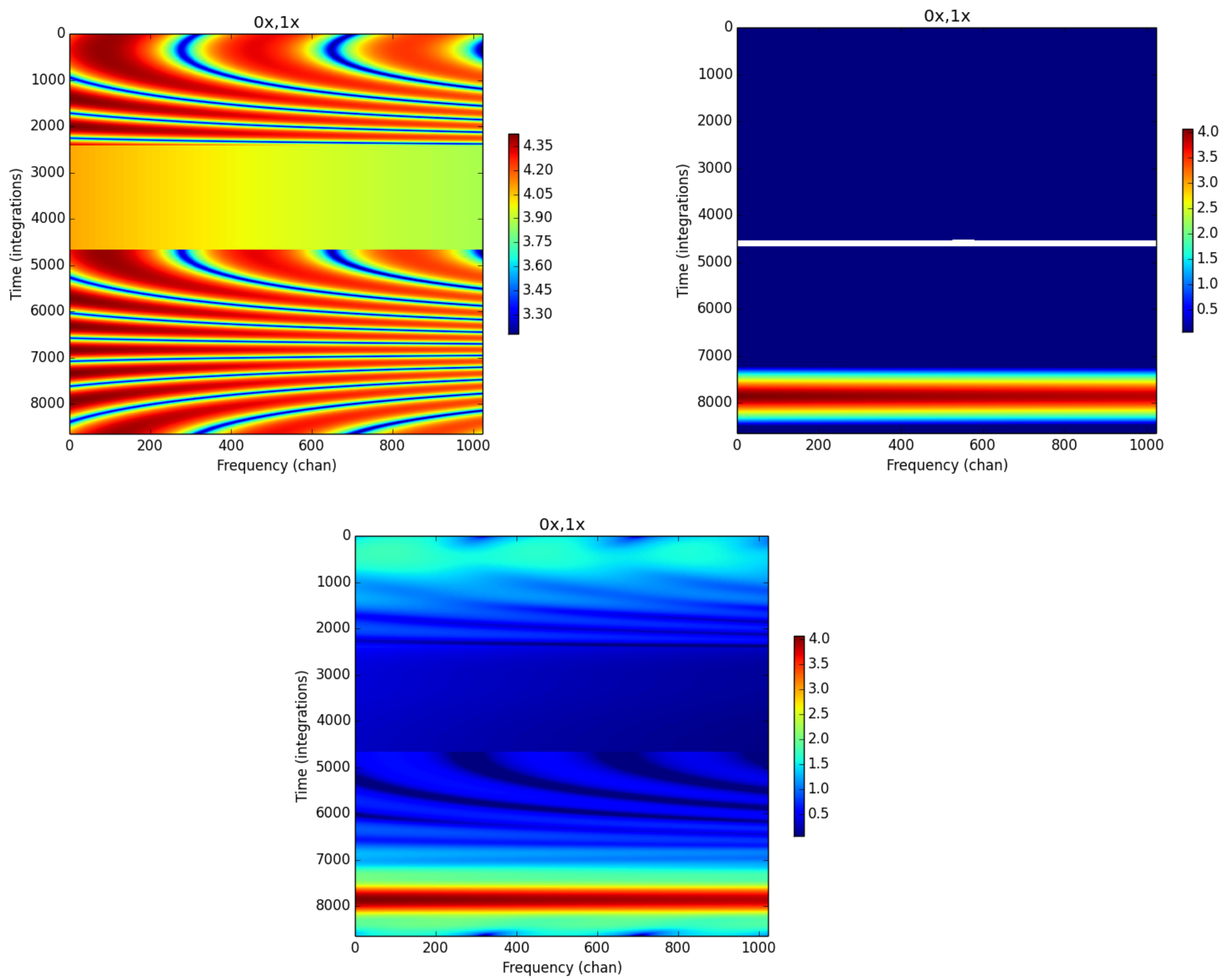

Fig. 2.— *Top Left*: Simulated visibilities with the flat beam. The sharp transition in the middle of the observation is due to the setting of Cygnus A below the horizon. *Top Right*: Simulated visibilities with the Gaussian beam. Cassiopeia A is not visible. *Bottom*: Simulated visibilities with the airy disk beam. The color scale in all plots is $\log_{10}(\mathrm{Jy})$.

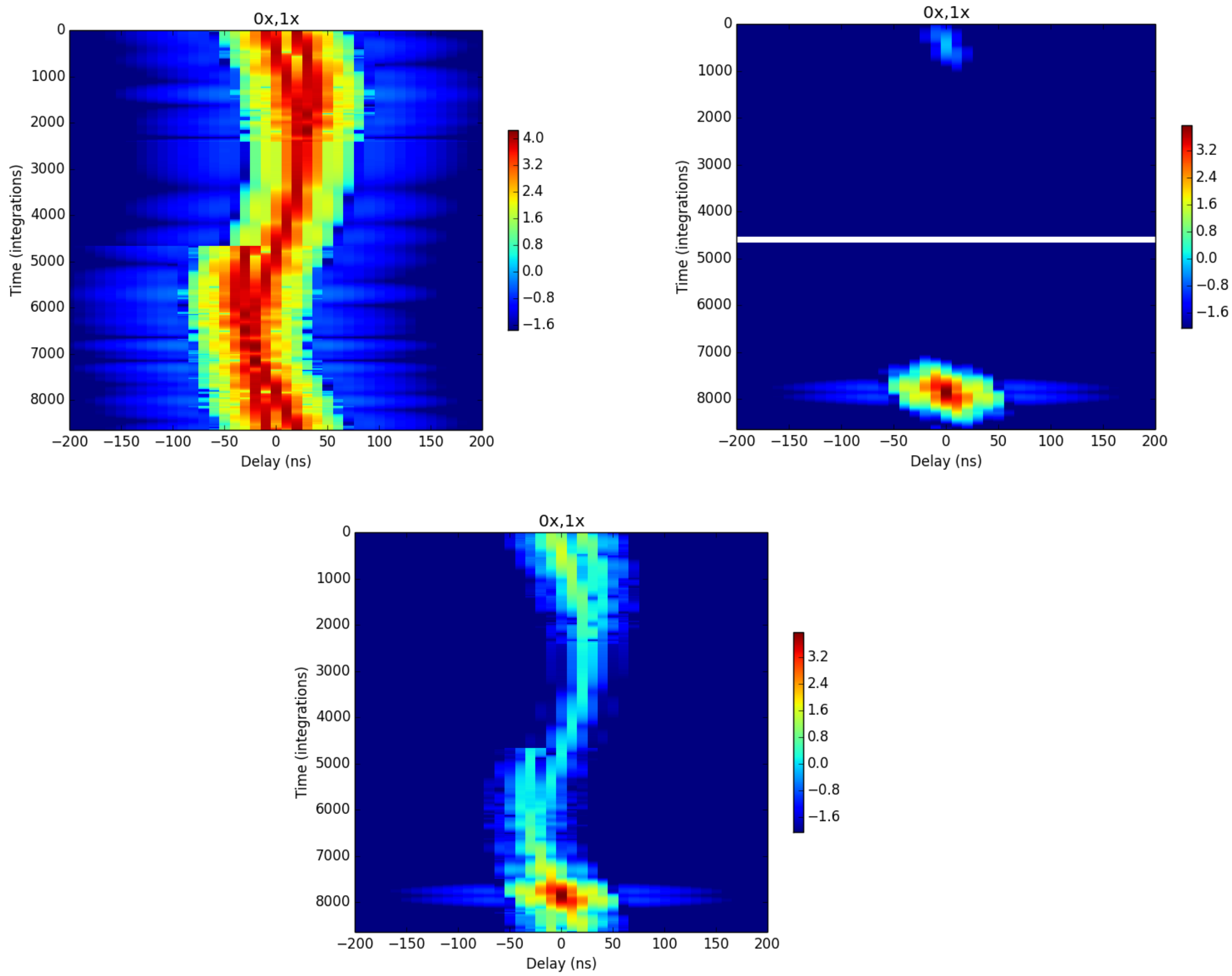

Fig. 3.— Delay transform for the flat beam (top left), the gaussian beam (top right), and the airy disk beam (bottom). The horizon limit on a 14 m baseline is ∼ 47 ns; the airy disk beam shows little to no evidence of additional supra-horizon power compared with the gaussian beam.

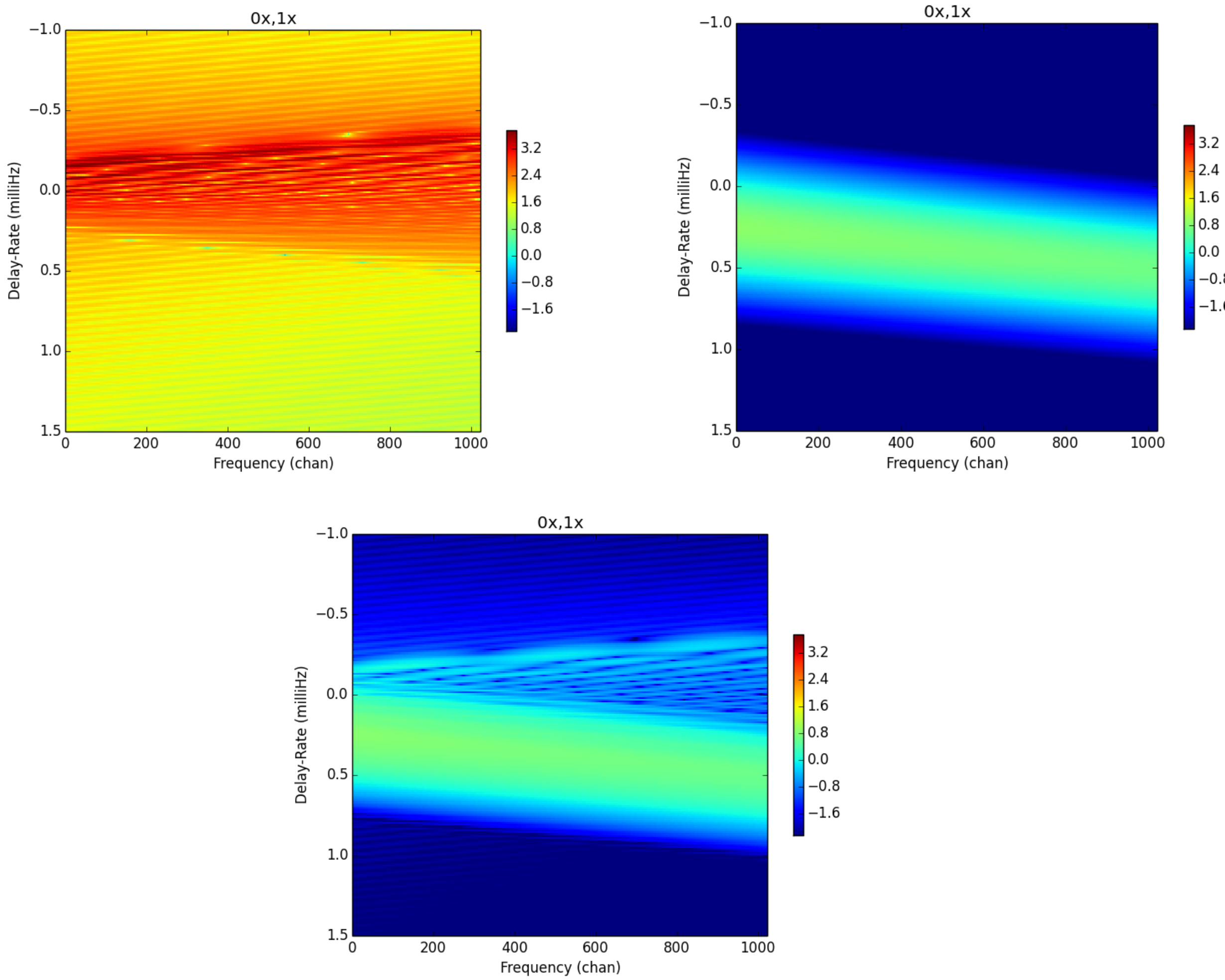

Fig. 4.— Fringe rate transforms for the flat beam (top left), the gaussian beam (top right), and the airy disk beam (bottom). The range of celestial fringe rates for a 14 m baseline span the range of ~ -0.75 to 1.25 mHz (c.f. Parsons et al. 2015). The airy disk beam does appear to show significantly more power and structure than the gaussian beam.

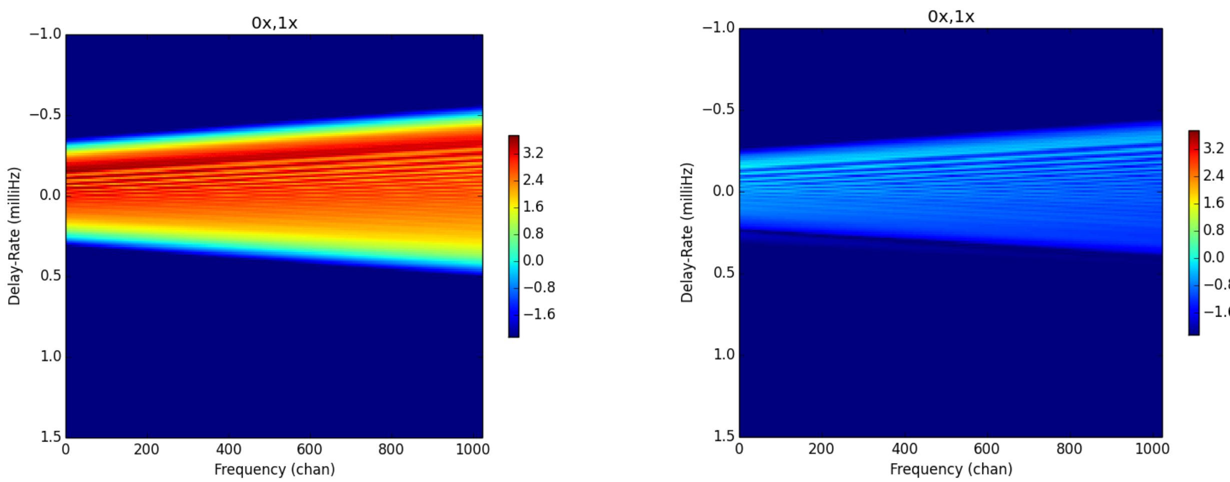

Fig. 5.— Fringe rate transforms for simulations including only Cassiopeia A with the flat beam (left) and the airy disk beam (right). The gaussian beam case is not plotted, since Cassiopeia A is not detected at a significant level in this model.