HYPERION Memo #1: The Relationship Between System Temperature and Sky Beam Coverage

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1 Introduction

In this memo, we seek to explore in further detail the idea of an interferometric study of the spatial monopole of the 21cm brightness temperature as a function of redshift (i.e. the "global signal"). In order to directly sample the zero-spacing mode of the sky, most previous studies of the global signal have been single-element experiments. However, it is our assertion that an interferometric approach can not only help to mitigate many of the systematics inherent to single-element experiments, but can also, given a clever experimental design and approach to data analysis, successfully sample the spatial monopole.

One of the modifications we can make to our experimental design is to artificially impose a spatial scale on the monopole through the creation of a horizon. From a Fourier perspective, the existence of the horizon interrupts the flat nature of the spatial monopole, which creates leakage from the DC-mode into modes with non-zero interferometric spacings. As discussed in Presley et al. (2015), a spacing of approximately one wavelength is ideal in balancing engineering constraints while maximizing reception of the spatial monopole.

We note in this memo that, by manipulating the scale of the horizon, we are similarly able to manipulate this Fourier leakage and thereby observe the monopole signal from other Fourier modes. By constructing absorptive beam-shaping baffles around the individual elements of our interferometer, we believe that we can optimize our proposed global signal interferometric experiment.

2 Simulation

The simulation calculates the system temperature as shown below in Eq. (1), where T_{sys} is the overall system temperature, T_{rx} is the receiver noise temperature, T_{abs} is the temperature of the absorptive baffle structures, T_{sky} is the sky temperature, T_{21} is the 21cm monopole brightness temperature, Ω is the full visible sky coverage from horizon to horizon, and Ω' is the baffle-modified sky coverage.

$$T_{sys} = \frac{T_{rx}\Omega + T_{abs}(\Omega - \Omega') + (T_{sky} + T_{21})\Omega'}{\Omega'} \tag{1}$$

For the purposes of this test, we have set some of the above parameters to be constants. The baffle absorber was set to be a standard blackbody with a temperature $T_{abs} = 300$ K. The overall sky temperature T_{sky} was calculated off of numbers presented in Rogers & Bowman (2008) and models presented in Haslam et al. (1982). With the initial brightness temperature measured to be $T = 237$ K at $\nu = 150$ MHz, Eq. (2) was implemented with a final frequency of $\nu = 70$ MHz and a spectral index $\beta = 2.5$ to receive a final galactic brightness temperature of approximately $T_{sky} = 1600$ K. Finally, the best estimate of the brightness temperature of the global sky signal is approximately $T_{21} = 20$ mK (Pritchard & Loeb 2010). We have iterated over an initial selection of $T_{rx} = 50 - 300$ K, as we believe these to be potentially attainable noise levels for a non-cryogenically cooled low-noise amplifier.

$$T(\nu) = T(\nu_{150})\Big(\frac{\nu}{\nu_{150}}\Big)^{-\beta} \tag{2}$$

In this simulation, we aim to determine the regime over which the baffle-limited beam will enable Fourier spreading of the global signal into neighboring spatial frequency bins while simultaneously ensuring that the sky remains the dominant term in the system temperature, as that will give us the best chances later of recovering the extremely faint 21cm global sky signal.

3 Conclusions

Pictured in Fig. 1, in a test with a fractional sky coverage Ω'/Ω ranging from 0.01 to 1, it is clear that the vast majority of the parameter space has a system temperature dominated by the absorptive baffles. From this plot, we can conclude that – at an absolute minimum – we must construct our absorptive baffles to admit at least 10% of the sky in order to ensure that the sky is the dominant term in our system. However, in order to ensure a system temperature of less than 6000 K, we will need to admit at least 20% of the sky. We can also conclude that the receiver noise temperature is a relatively minor contributing factor to the overall system temperature, and that the experiment will not be strongly affected by the selection of cheaper 150 K amplifiers over more costly, lower noise options.

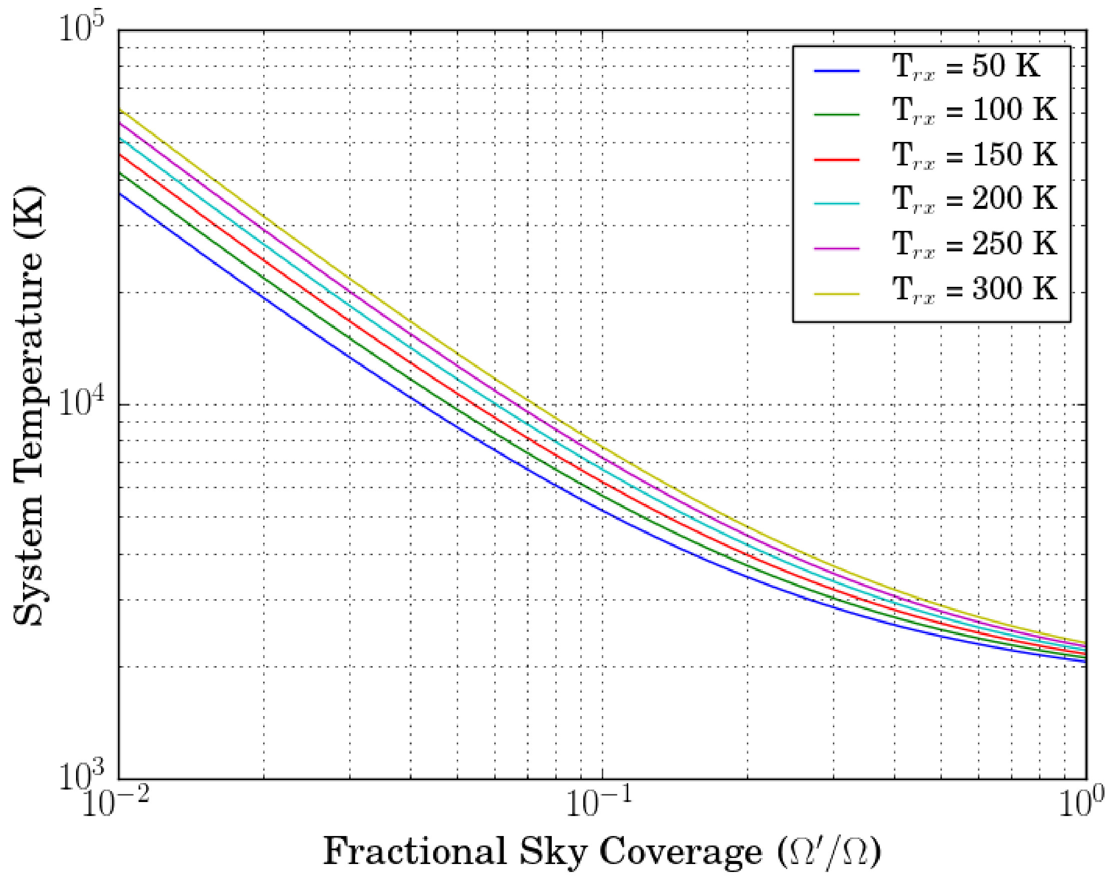

Figure 1: Pictured above is the relationship between the fractional sky coverage as determined by the beam-limiting baffles and the overall system temperature. It is readily apparent that below 10% sky coverage, the system temperature is completely dominated by the presence of the 300 K baffles.

References

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