Basic Design Considerations for a Global Signal Interferometer

Summary of Presley, Liu, & Parsons (2015)

Raul A. Monsalve

Introduction

- Most global experiments to date have been **single-element** experiments.
- An **interferometer** can be designed to be **sensitive to the monopole** mode of the sky.
- Interferometers are able to avoid a number of **systematics** inherent in single-element experiments.
- Interferometers avoid the systematic **noise bias** that has to be calibrated and subtracted off in a single-element experiment.
- This noise could have significant **spectral structure**.
- The paper **does not consider** the effect of **mutual coupling**.

Sensitivity to Monopole

- An interferometer **correlates the integrated electric fields over the effective apertures** of the antennas forming the baseline. We therefore measure the visibilities

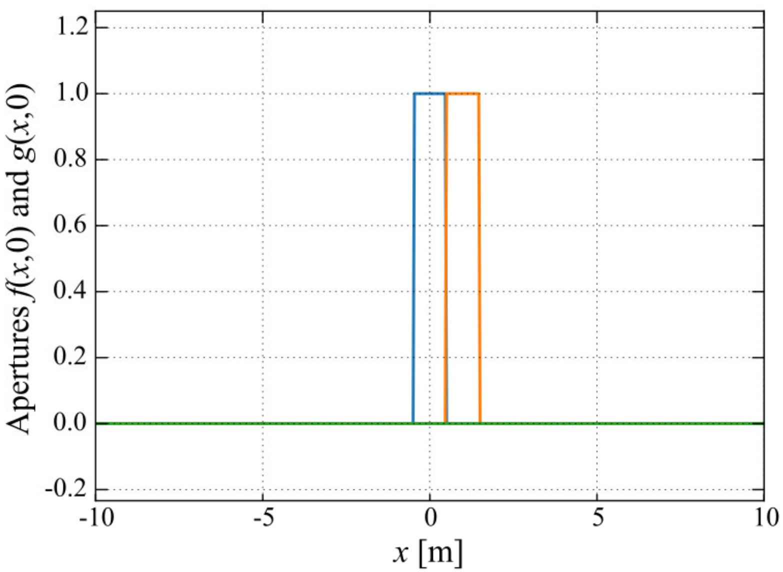
$$V \propto \int d^2\boldsymbol{x}_1 d^2\boldsymbol{x}_2 f(\boldsymbol{x}_1) g(\boldsymbol{x}_2) \langle E(\boldsymbol{x}_1) E(\boldsymbol{x}_2)^* \rangle$$

- The **spatial dependence of the primary beam** and the **finite curved extent of the sky** prevent the interferometer's response from integrating to zero.

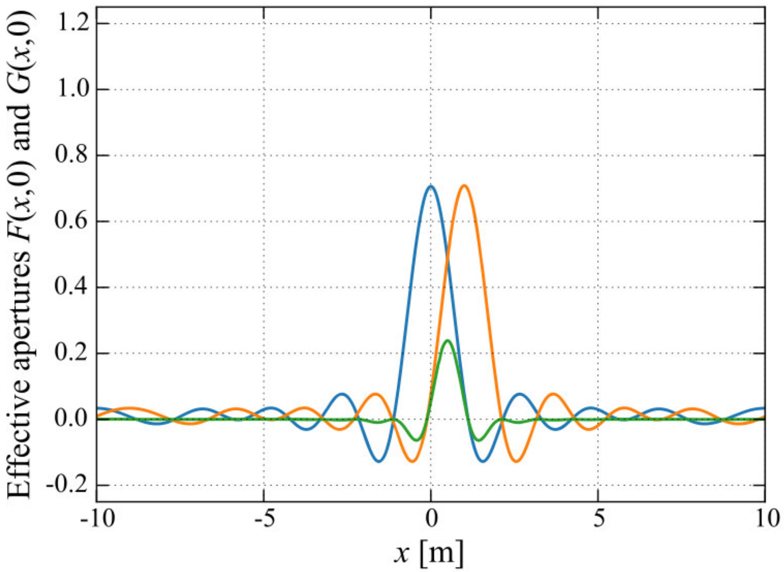
- Assuming the sky emission is constant and equal to T_0:

$$V \propto T_0 \int d\boldsymbol{x} F(\boldsymbol{x}) G(\boldsymbol{x})$$

Sensitivity to Monopole



Idealistic, **non overlapping** apertures



More realistic, **overlapping** apertures

Design Considerations: Baseline Length

- The **optimal baseline length** is given by

$$\frac{b_{\text{opt}}}{\lambda} = \frac{1}{2\pi\theta_b}\sqrt{\frac{\alpha}{2}}$$

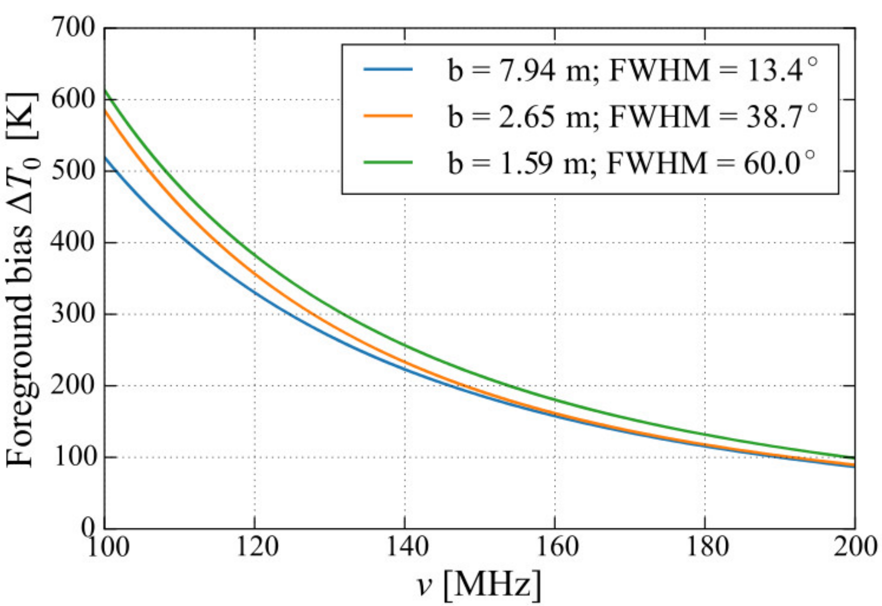
- It minimizes the bias and the variance in the estimation of the global signal.

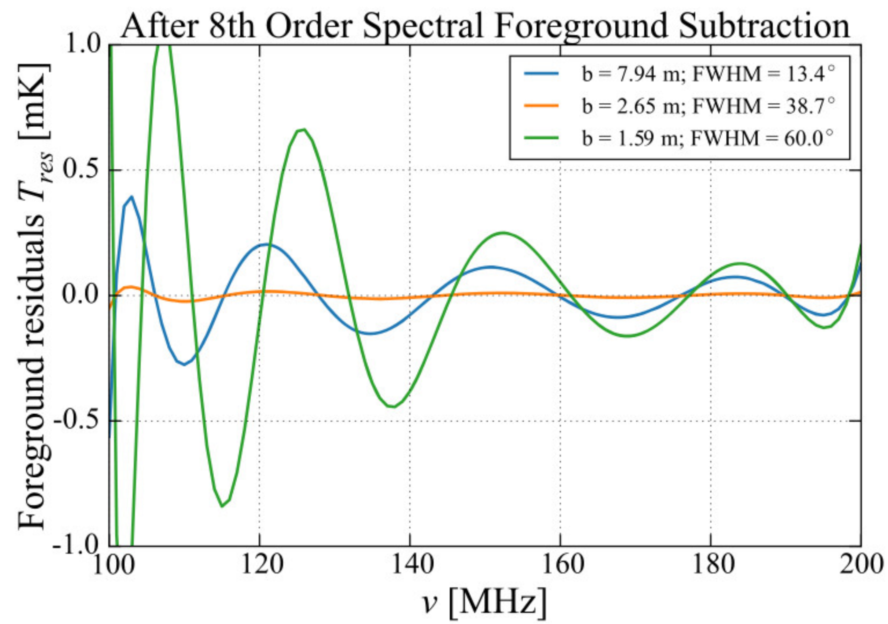
- This length is **comparable to the radius of the antenna**.

- Therefore, **closely packed arrays are desirable**, as close together as physically possible.

Design Considerations: Primary Beam Width

- A **lower limit of 2°** is imposed by the need to measure a good representative of the global signal.
- A **narrow beam** minimizes measured foreground level but **introduces spectral ripples**.
- Therefore, an **intermediate beam** size is the **best compromise**.





Design Considerations: Number of Elements

- In an array, individual baselines are **less sensitive** to the global signal than a single-element experiment.

- **To match the signal to noise** for the same integration time, **how many baseline copies** are necessary?

$$N_{\text{short}} \approx \frac{\left| \int A(\hat{\boldsymbol{r}}, \nu) d\Omega \right|^2}{2 \left| \int A(\hat{\boldsymbol{r}}, \nu) \exp\left(i 2\pi \frac{\nu}{c} \boldsymbol{b}_{\text{short}} \cdot \hat{\boldsymbol{r}} \right) d\Omega \right|^2}$$

- For a closely packed NxN array, **the answer is N=3**, for a total of 9 elements.

Simulations

- They simulated observations with a **6x6 array**, and **compared** results to those from a **single-element** experiment.
- 50-100 MHz
- FWHM 40° at 50 MHz, and proportional to λ
- Foreground model based on Haslam map
- Cosmological signal:

$$T_{\rm dip}(\nu) = -A \exp\left(-\frac{(\nu - \nu_0)^2}{2\sigma^2}\right)$$

1. Pessimistic pre-reionization scenario, with $(A,\ \nu_0,\ \Delta z) =$ (10 mK, 60, 10 MHz).
2. Moderate pre-reionization scenario, with $(A,\ \nu_0 \Delta z) =$ (100 mK, 70, 5 MHz).
3. Optimistic pre-reionization scenario, with $(A,\ \nu_0,\ \Delta z) =$ (200 mK, 80, 5 MHz).

Simulations

Orange: interferometer