Calibrating PAPER Receiver Temperature Using a Galactic Synctrotron Model

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1. Generating a Model of the Galactic Synchrotron

A model of the temperature distribution across the sky was obtained from the Foreground Products page of the Legacy Archive for Microwave Background Data Analysis[1]. Since the map was made with an angular resolution better than necessary for our purposes, the map is scaled down from 3145728 pixels to 49152 pixels to speed up computation. The temperature at 162 MHz is then determined by

$$T_{162} = T_{408} \left(\frac{162}{408} \right)^{-2.55} . \tag{1}$$

A table is read out with these temperatures and their corresponding right ascension and declination, as calculated from the galactic coordinates of the original map with the IDL routine glactc.pro[2].

These temperatures are now convolved with the antenna gain for one dipole, as provided by Rich Bradley, for each instance of time. The model was created in mid-October and includes the ground-screen. This step is done by discrete convolution, so the model as a function of Local Sidereal Time is

$$T(t) = \frac{\sum T(HA, \delta) D(HA, \delta)}{\sum D(HA, \delta)} \tag{2}$$

where right ascension has been converted to hour angle, $T(HA, \delta)$ is the Haslam map temperature, $D(HA, \delta)$ is the gain in a given direction, and the sum is over all points in the map. Calculations are done for each instance of time in LST, using coordinates of altitude and azimuth. The temperature is set to 300 K for points with an altitude lower than 6 deg.

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[1]http://lambda.gsfc.nasa.gov/product/foreground/f_products.cfm

[2]From the IDL Astronomy User's Library at http://idlastro.gsfc.nasa.gov

2. Data Preparation

The IDL routine lst_auto.pro (residing in Green Bank at /home/scratch/ngugliuc/idl) reads in a user specified length of data and finds the median power for a set of "good" channels. The default channels are 145 to 154, corresponding to 160 MHz and 165 MHz. Then the Local Sidereal Time is calculated for each observation using the longitude and latitude of the Green Bank Telescope.

When the temperature vs. LST for the Haslam model is compared with power vs. LST for the data, they have similar functional forms (see Figure 1). Major outliers are removed from the data and the data and model are each fit with a six degree polynomial. The results of these fits can be seen in Figure 2. Now, using these polynomial fits to create a model of temperature and of power that are on the same timescale, the data is shifted in LST such that the peaks in temperature and power line up. This is indication of an error in calculating the LST of the data. Finally, the data and temperature can be directly compared in order to find acharacterize the receiver temperature.

3. Fitting for Receiver Temperature

The power of a radiometer can be described as

$$P = gkT\Delta\nu \tag{3}$$

where P is power in erg s^{-1}, g is the gain, k is Boltzmann's constant as 1.38×10^{-16} erg K^{-1}, T is the temperature in Kelvin, and $\Delta\nu$ is the bandwidth in Hz. The temperature is the antenna temperature plus the receiver temperature, such that

$$P = gk\Delta\nu(T_{mod} + T_{rec}). \tag{4}$$

With a model for the antenna temperature from the Haslam survey and the power from our data, we should be able to derive the antenna temperature by plotting the temperature of the model vs. the power for matching LST. This uses the fitted data and model described above. Then, a linear fit can be found such that

$$p = aT_{mod} + b \tag{5}$$

and T_{rec} is b/a. The constant a is a $gk\Delta\nu$.

Various attempts to find T_{rec} are failing, that is, giving T_{rec} that are unreasonable (see Figure 3). Various methods have been tried to improve this, such as just using nightime data and just using data for when the galactic place is overhead. However, even when the data to be fit is nearly linear, as shown, the receiver temperature comes out negative.

4. Exploring More Data Sets

This fitting has been done with antenna 1 from September 7 to September 10, before the move to longer baselines. Figure 4 and Table 1 show the results for antennas 2, 4, 6, and 8 during the same time frame. These antennas were not moved in any way during this run, and I have cut off the data before the move since that seems to have affected the power levels for all the antennas. Note that the T_{rec} is still negative and varies by tens of degrees. The gain, as expected, also changes between antennas.

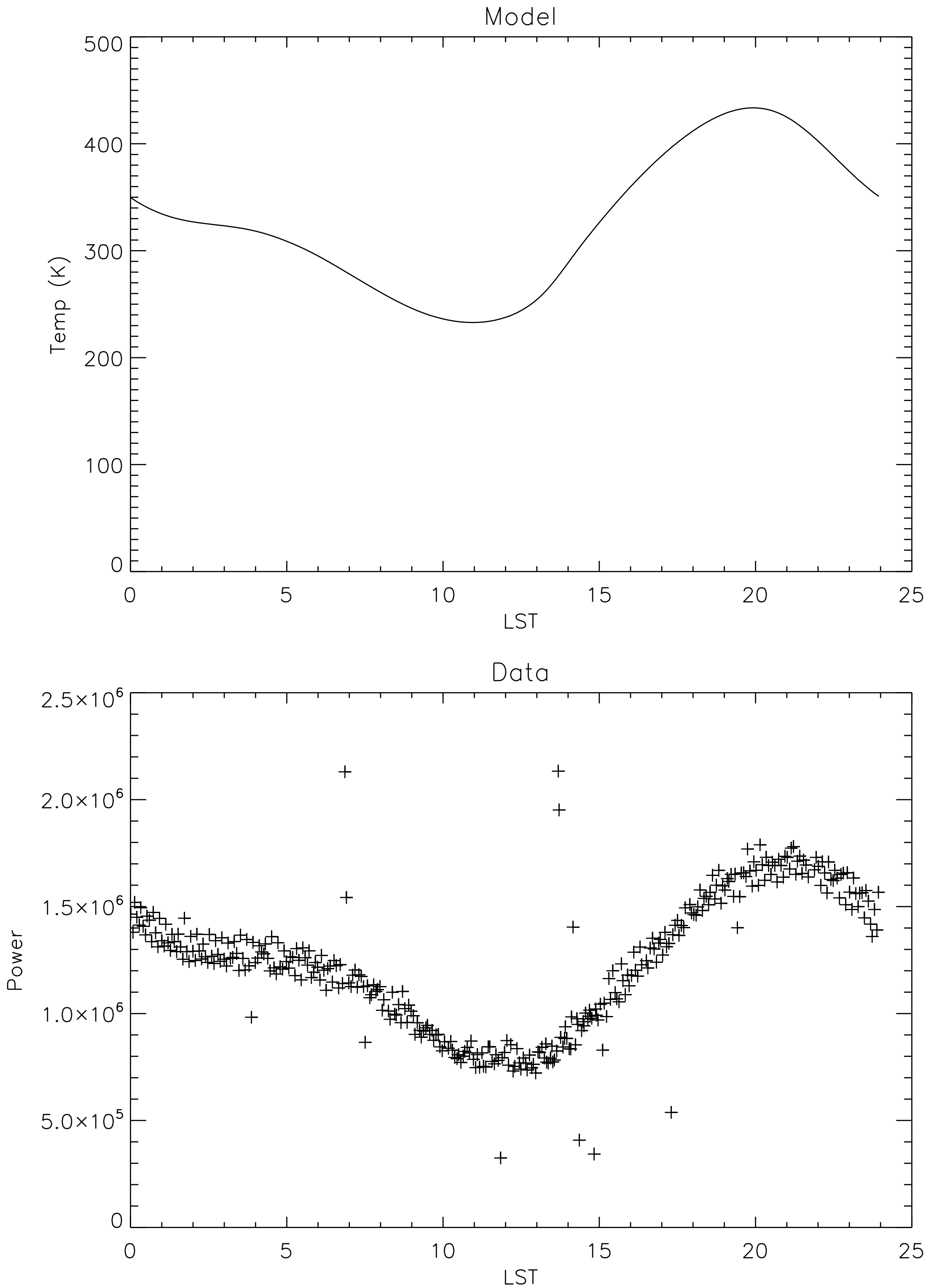

Fig. 1.— Model temperature vs. LST and data, in arbitrary power units, vs. LST. This example is for the first few days of the September run for Antenna 1.

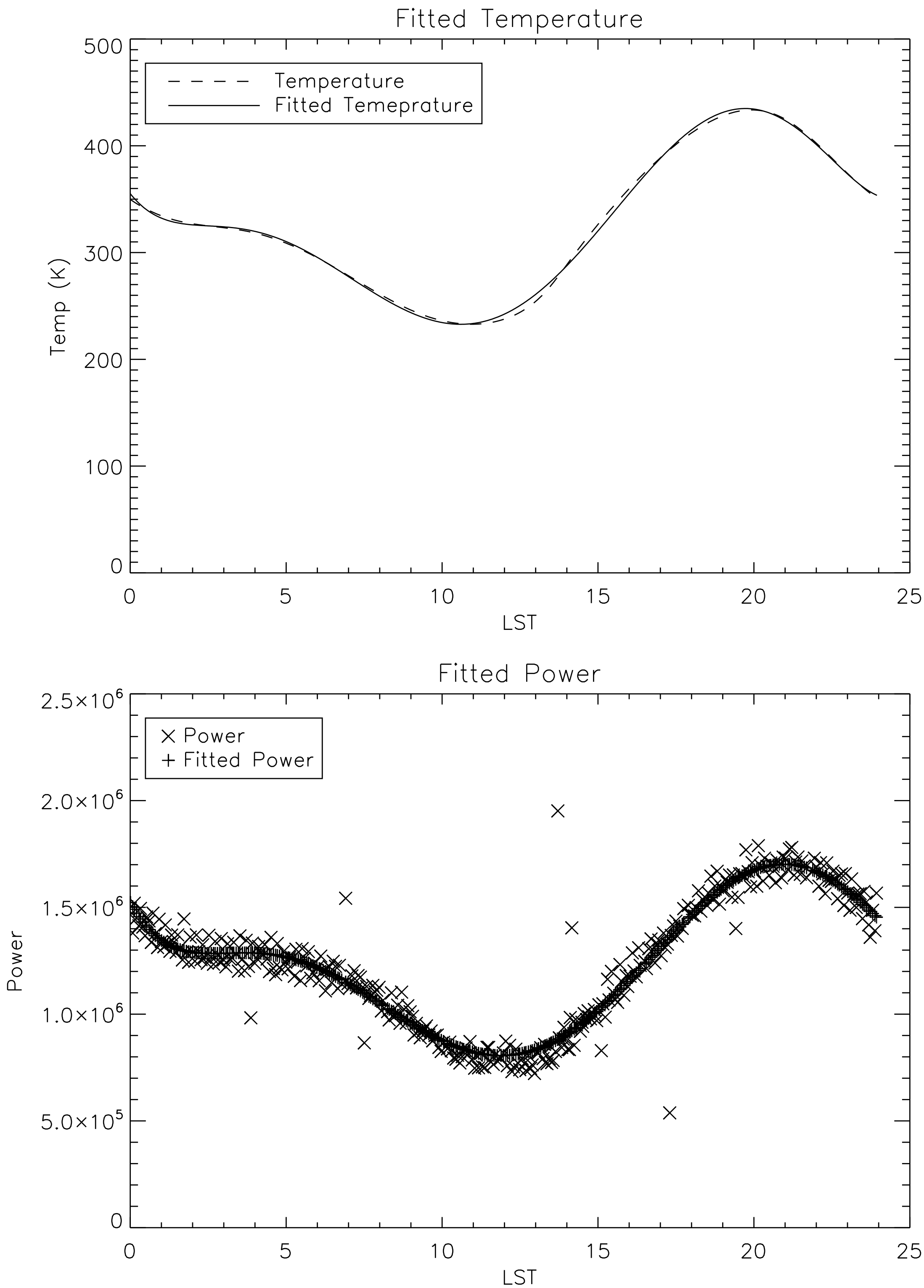

Fig. 2.— Polynomial fits of the temperature model and data power plotted with LST.

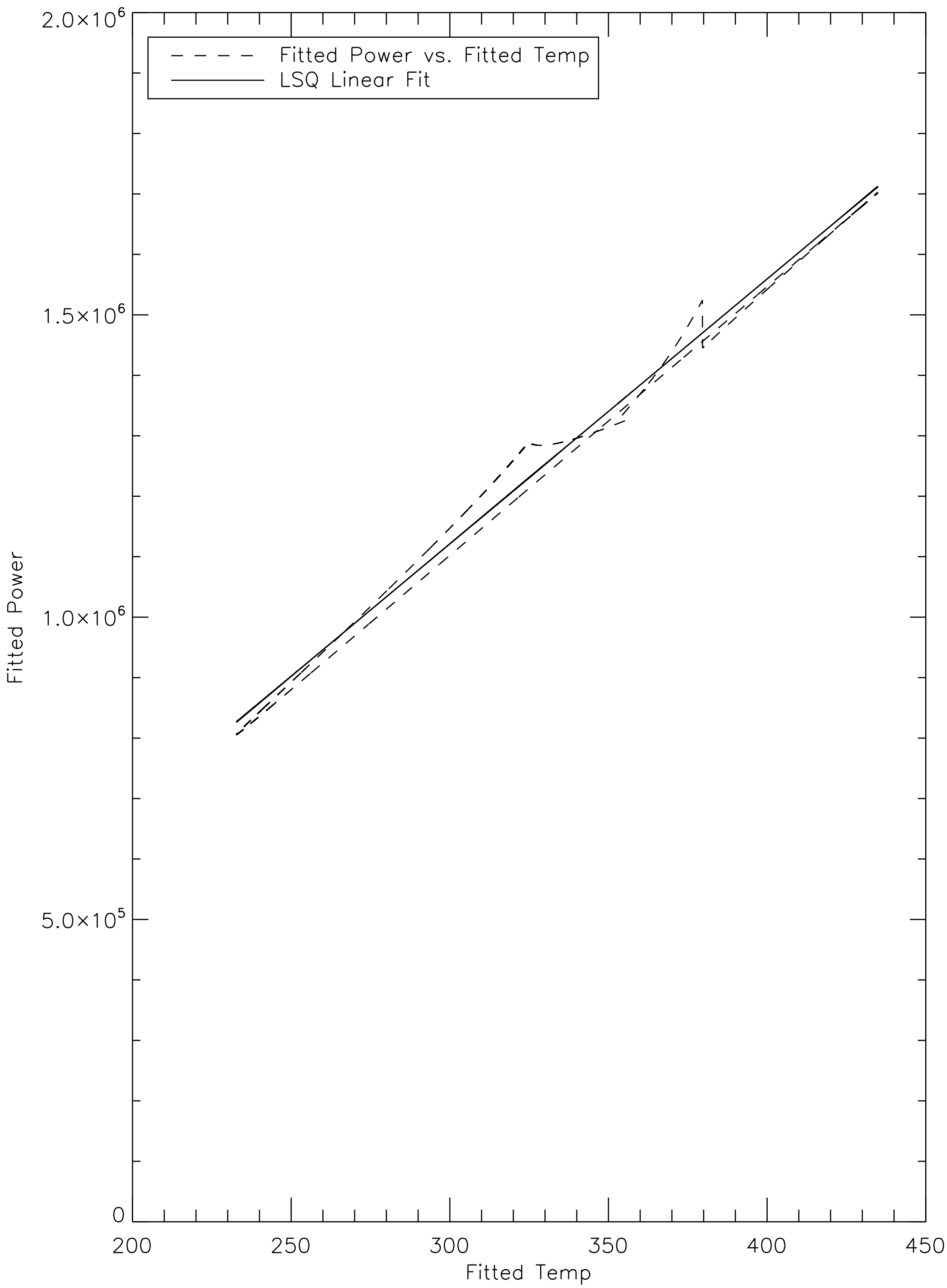

Fig. 3.— Linear least-squares fit of the fitted power and temperature. Note that this gives a receiver temperature of −44 K.

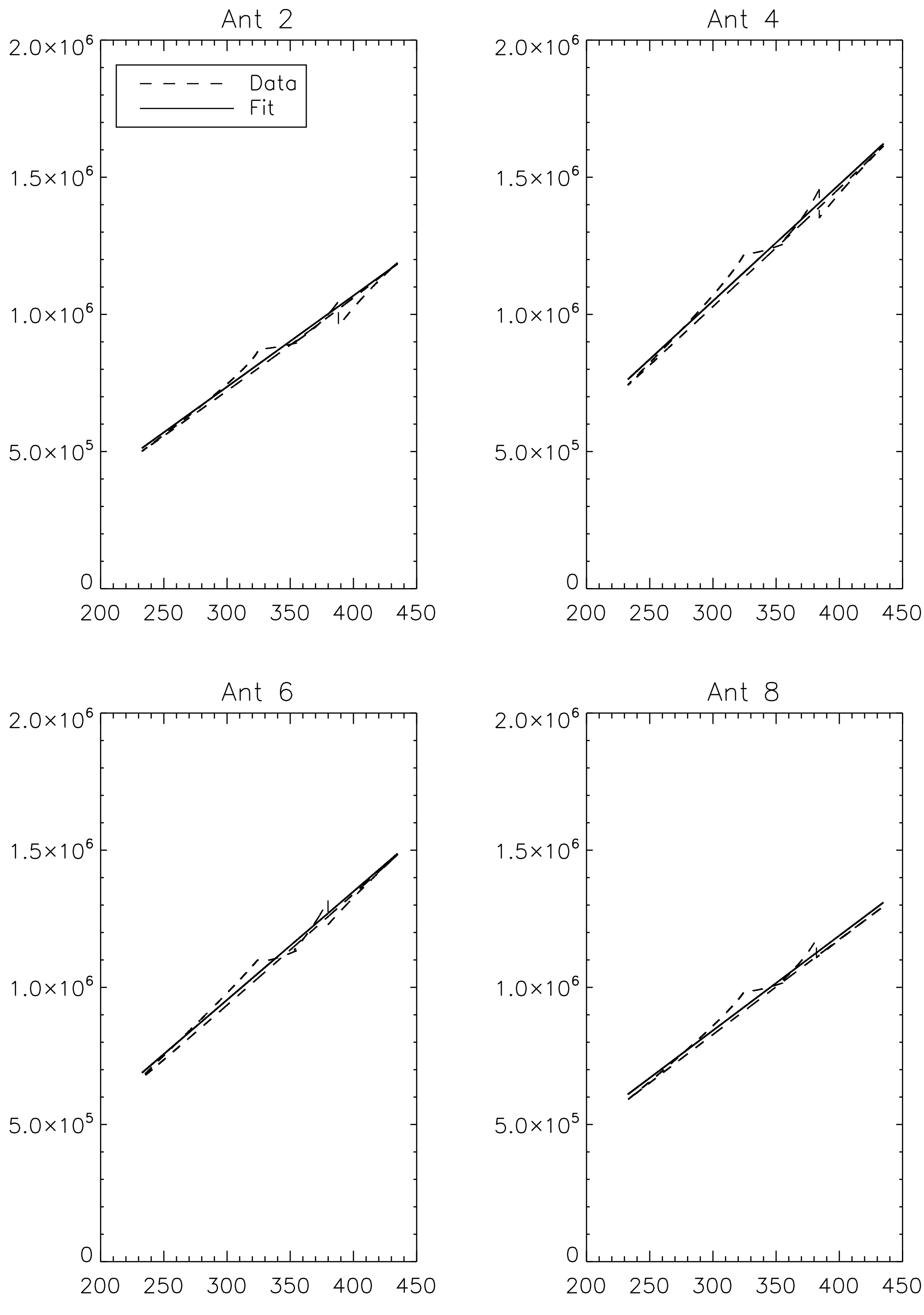

Fig. 4.— Fits for different antennas Sept 7 - Sept 10. Fit parameters are in Table 1.

Table 1. Results for Different Antennas

Antenna	T_{rec}	Gain*BW*k
1	−44	4381
2	−78	3323
4	−53	4249
6	−58	3951
8	−56	3460