Observing the Sun, Moon, Orion and Crab Nebula using a two-element interferometer

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Abstract

Using an two-element inteferometer we observed the Sun, Moon, Orion and the Crab Nebula. From the data obtained for the Crab Nebula we applied least squares filling to determine the best guess for our baseline which resulted to be around 8 meters. Similarly, least-fitting the data from the Sun, we obtained the phase differance between the two antennas and this resulted to be around 0.2 radians.

1 Introduction

In this lab we focus on understanding basic interferometry. We used two antennas to obtain observational data from the Sun, moon and Orion. These are all considered continuum sources so our telescopes are able to detect them. We wrote a computer script that would allow us to position the antennas in the right direction for each source. Observations were taken from Horizon to horizon for the moon and the sun. Orion was observed for a couple of hours. The method of least square fitting was used to obtain information like the size of our baseline, the radius of the Sun and moon and the declination of our point source, Orion.

2 Methods

For the gathering of the data we used two antennas located on the roof of a building. This technique is called interferometry and it is very commonly used in Radio Astronomy. We wrote a computed program that controlled where the atennas point in order to obtain our data. Determining the location of our sources of interest was very import in the accuracy of our results. We then analyzed the data using a method of least-square fitting. This allowed us to determine the radius of Sun and Moon and also the declination of Orion.

2.1 Interferometer

An interferometer consists of two antennas separated by some distance called a baseline. The two antennas collect a signal which is then processed through a complicated circuit to give a graph on the computer. The graph that results from the interferometer is called a fringe pattern and it represents the complex response of the baseline along the sky. The fringe pattern looks very close to a sine wave. Therefore, in our observation we expect to see a fringe pattern that looks a bit like a sine wave for each source.

The interferometer we used operates at about 11GHz. It has a short baseline and the fringe spacing is large than the size of all sources, except when we observe the Sun and Moon, so they can be considered as point sources.

Because the Sun is the brightest object in the sky, it is easy to obtain a clear fringe pattern. this is why we determine the value of our baseline from the Sun observations. With the baseline value, the fringe properties represent the declination of the point-source which in our case is Orion. Our baseline is 10m and this means we have a fringe spacing of 10' and with a horizon-to-horizon observation we can measure the declination more accurately. This is precisely why we are taking horizon-to-horizon measurements for the Sun and Moon. From this observation of the Sun and Moon we can measure their diameters to a fraction of a percent.

The way our interferometer works is it takes the two signals from each telescope and multiplies them together via a mixer. The data we end up recording is the time average of the product of the signals over a time interval of a few seconds. The multiplication of the two signals is done through a cross product because this allows the average value to be zero unless there is a source. This ensure us that any detected signal is coming from the source only. For a particular source, the fringe amplitude has no zero offset and it is directly proportional to the source flux.

2.2 Rotational Matrices

In order to get our observations we need to know the azimuth and altitude of the source so that the telescopes can know where to point. The azimuth and altitude of the Sun and Moon can easily be obtained at any given time using the PyEphem module. However, The azimuth and altitude can also be calculated using a rotational matrix, R, and the values for the sources right ascension and declination. The way the rotational matrix works is by you dotting the matrix containing the values of the right ascension and declination for a source with the rotational matrix R to give a resulting matrix containing the values of the azimuth and altitude for that source. In our case, the Sun and Moon have a changing right ascension and declination therefore we have to account for the changes in position with time. For our point source Orion there is a set value for the right ascension and declination.

2.3 Least-Squares Fitting

Least-squares fitting is a method for approximating the solution for a set of data. In our case we are using this method for the approximation of Moon and Sun radius as well as the declination of our point source. In order to do this, we start by reading a data file and transferring the numbers to a matrix using IDL commands. What follows are a series of steps that will allow us to plot our data fitted to the approximate solution which in our case is a sine wave. With this plot we have the necessary information to determine the approximate radius of the Sun and Moon.

3 Results and Discussion

We observed the Sun and Moon from horizon-to-horizon and Orion and the crab nebula for approximately 4 hours. From this a plot of voltage vs time was obtained for each source.

3.1 Orion and Crab Nebula Observation Results

The signal for Orion and Crab Nebula are show in Figure 1 and 2. For Orion we have a bit of strange data in the beginning but it ends up becoming steady after some time. The voltage seems to stay between -0.0005 and -0.0010 volts. The negative voltage/power values come from the fringe pattern of the source. For the Crab Nebula the data around the middle of Figure 2 is what we expect. Then parts where the voltage fluctuates a lot must be due to some inteferance. From this plot of the Crab Nebula, we applied least square fitting in order to get the best guess for the baseline of our telescopes. We did this by guessing different values for the baseline and calculating the error of each value. A plot of this is show in Figure 3. In this figure we look for the minimum y value and the corresponding x value is our best guess for the baseline. We therefore conclude that the baseline is around 8 meters.

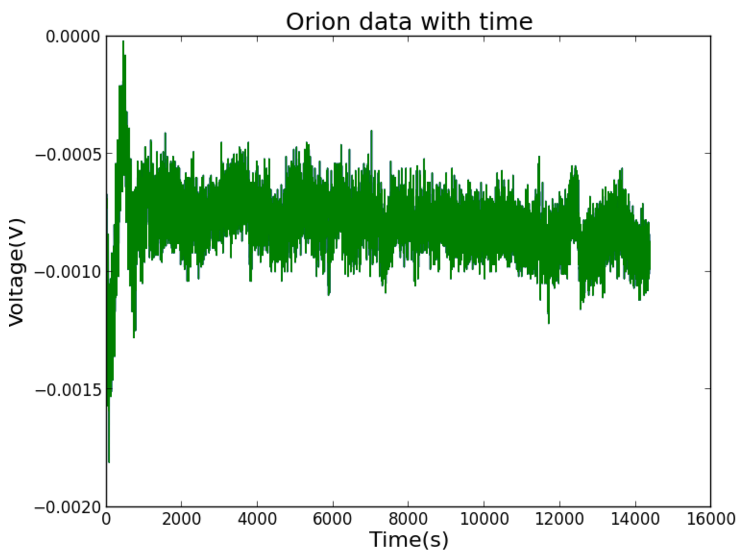

Figure 1: A plot of the signal of Orion with time using an interferometer.

3.2 Sun Observation Results

The Sun signal with respect to time is shown in Figure 4. If we zoom in on this graph we can see the sine wave that represents our fringe pattern. This is shown in Figure 5. The negative values of voltage or power come from the fringe pattern. Unlike the point sources, we get a pretty nice sine wave for the fringe patter because the Sun is so big and bright in the sky, which is why the Sun was a great tested for our script to control the telescopes. We went on to applying least square fitting to the Sun data in order to find the phase differance

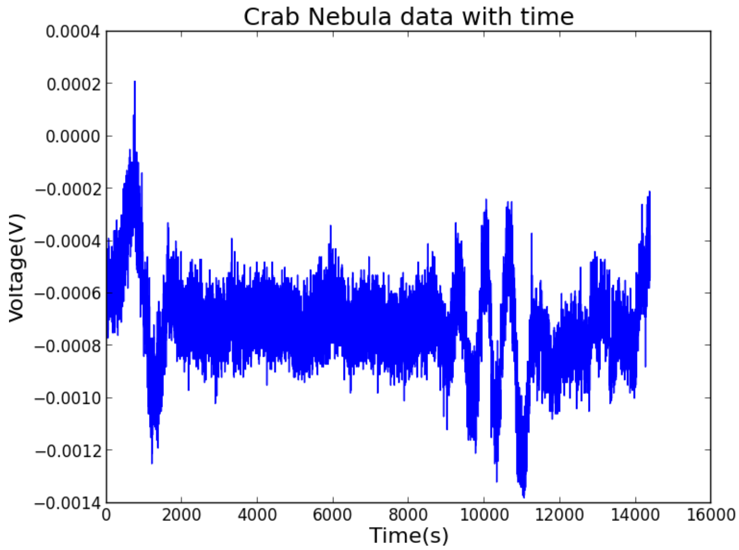

Figure 2: A plot of the Crab Nebula signal with time using an interferometer

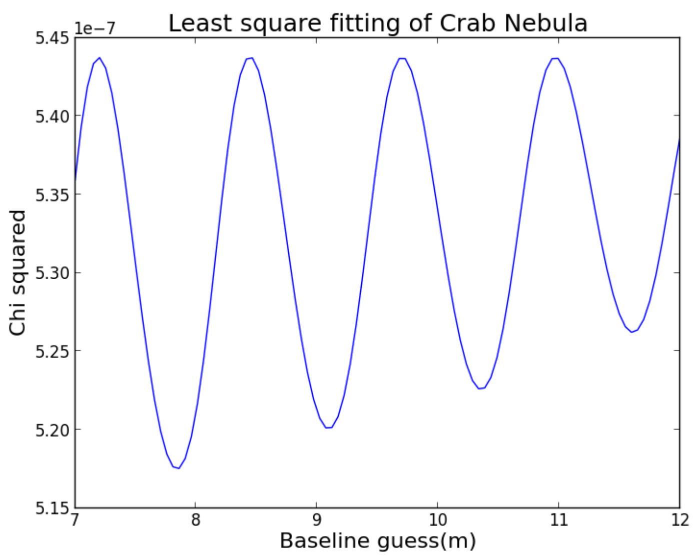

Figure 3: The error associated with various guesses for the baseline of our interferometer.

of our antennas. This phase difference, phi, comes from the fact that the signal from one antenna differs for the other. This difference is proportional to the baseline. The plot for the guesses for phi and their corresponding error with our data is shown in Figure 6. We look for the minimum value of y and the corresponding x value will give us the most accurate phase differance. We can conclude that the best guess for the phase differance is approximately 0.2 radians.

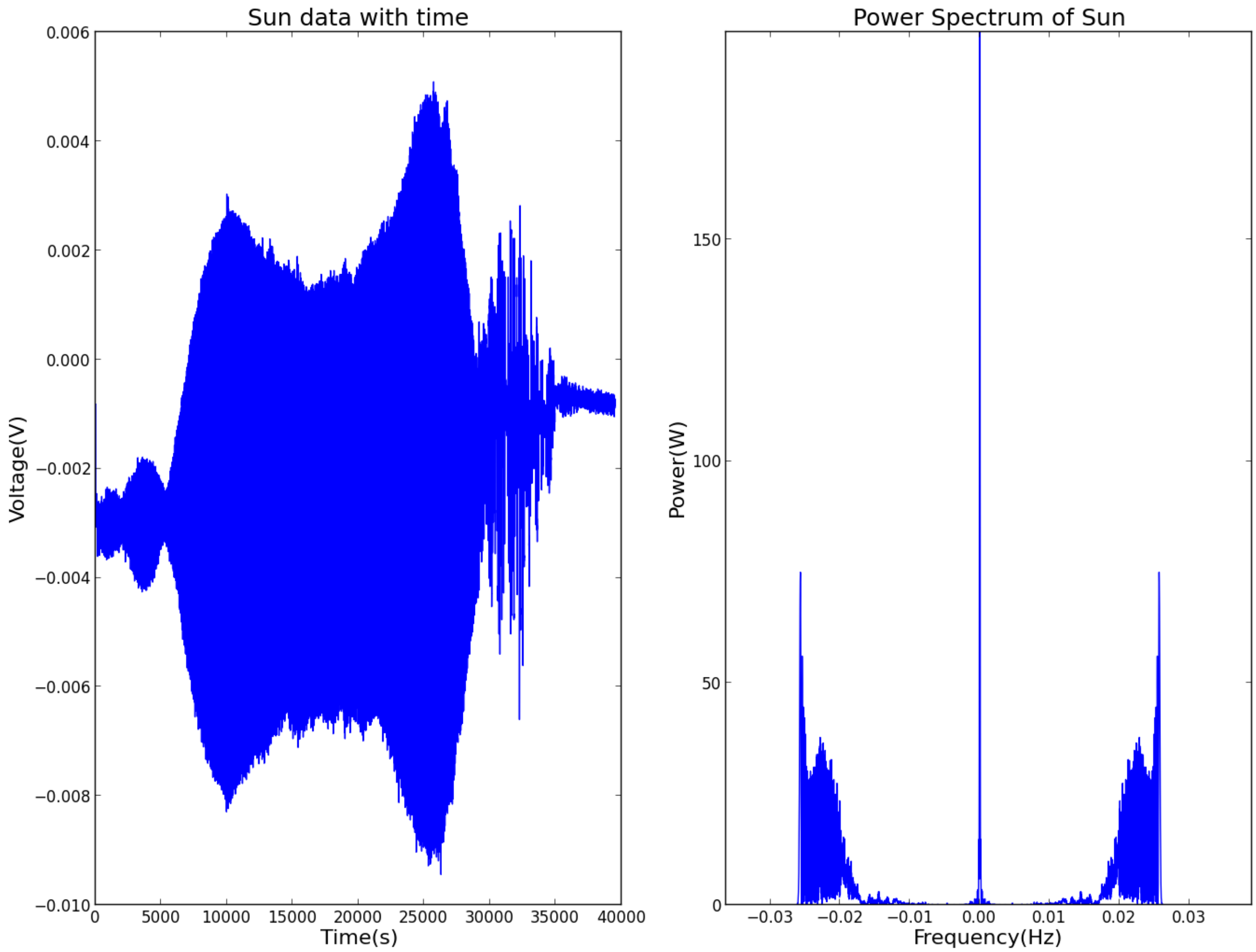

Figure 4: A plot of the Sun signal from horizon-to-horizon using an interferometer

3.3 Moon Observation Results

The signal for the horizon-horizon observation for the Moon are shown in Figure 7. We would expect to the something a little better than what we got because the Moon is so big. There is a lot of noise which can result from the actual script used for the observation and the phase of the moon. We still performed a least square fitting to this data and this is shown in Figure 8.

4 Conclusion

In this lab we were able to use least square fitting on the data from the Crab Nebula to find the best guess for the baseline of our antennas. In the future we would like to explore other

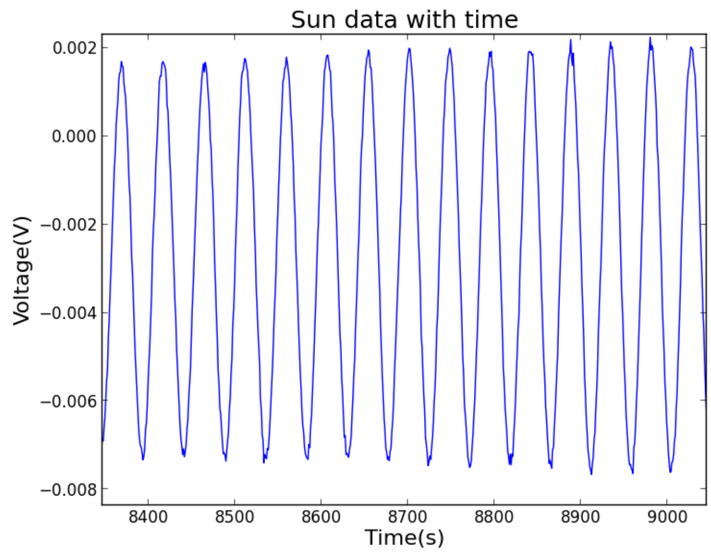

Figure 5: A zoomed in vesion for the plot of the Sun signal form horizon-to-horizon using an interferometer

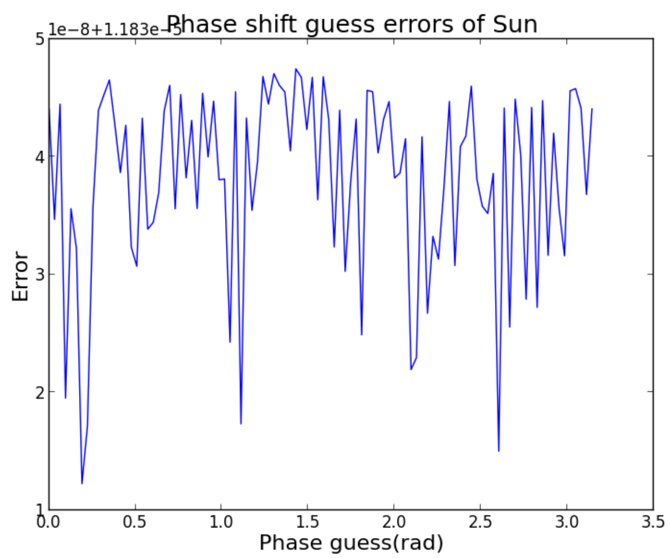

Figure 6: The errors associated with various guesses for the phase difference, phi, for the Sun data.

information about our data using least-square fitting like the radius of the Sun and Moon.

5 Acknowledgements

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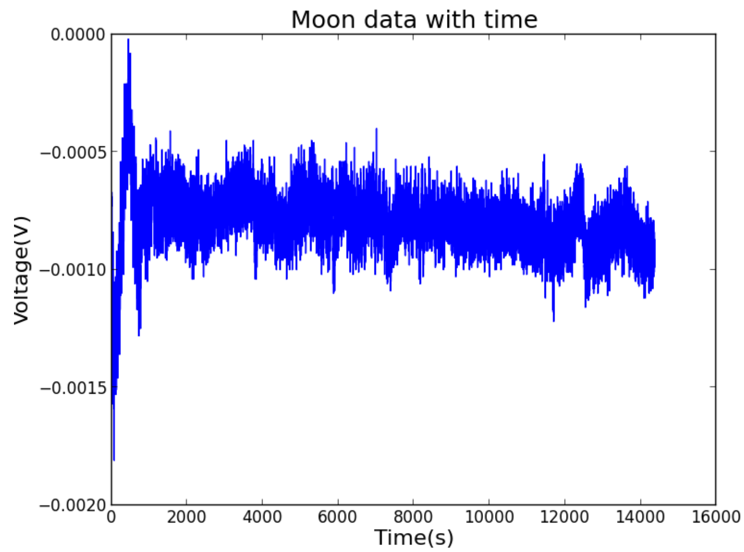

Figure 7: A plot of the Moon signal from horizon-to-horizon using an interferometer

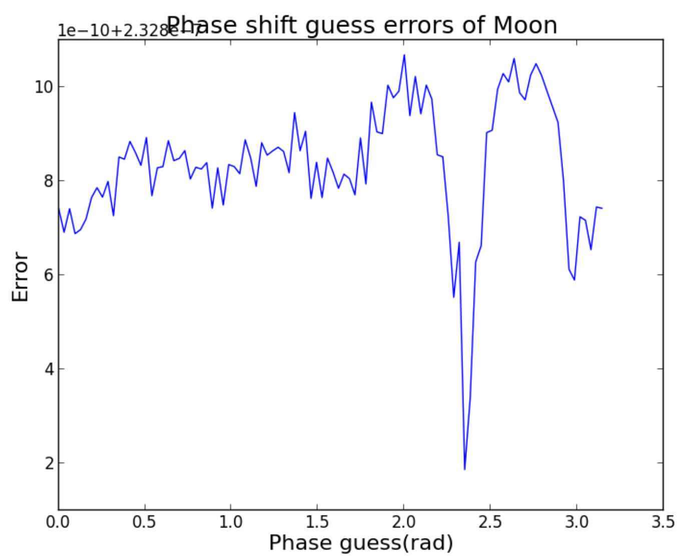

Figure 8: The errors associated with various guesses for the phase difference, phi, for the Moon data.

Bordwell and Karto Keating for their contribution in the analysis of the data.