CHAPTER 5: TESTING RESULTS

As telescope time is very valuable, only ten sets of data were taken to test the throughput increase with the use of tip/tilt. Each test set includes one observation with the tip/tilt feedback loop open and one closed loop observation. The number of counts seen by the spectrograph for each observation and the throughput increase was calculated as shown in Table III. The test sets were made with all tip/tilt components in place for both open and closed loop observations. The ideal losses through the mirrors and beamsplitter will be approximately 11.5% after the mirrors are Silver coated, resulting in the theoretical throughput increase, in the last column of Table III, simply being the difference of the observed increase and the ideal losses.

Throughput Improvement

The data was taken over the course of three nights for a variety of seeing conditions. It was observed that even while the seeing appeared good and tip/tilt was thought unnecessary, throughput gains were achieved. During very bad seeing, throughput increases of up to 170% were observed. During these conditions the objects were seen to leave the slit occasionally, but far less than during open loop operation and they returned much quicker. Two of the test sets are worth noting. Set #7

Table III. Testing Results

Test Set	Object	Open Loop Counts (dn)	Closed Loop Counts (dn)	Increase (%)	Theoretical Increase W/Ideal Optics (%)
1	HR765	2900	5000	72.4	60.9
2	HR1165	1900	4800	152.6	141.1
3	HR1165	1200	2500	108.3	96.8
4	HR1165	1300	3500	169.2	157.7
5	HR1165	2300	2800	21.7	10.2
6	HR1165	850	1600	88.2	76.7
7	HR7602	5400	3100	-42.6	-54.1
8	HR864	900	1700	88.9	77.4
9	HR864	1280	1800	40.6	29.1
10	HR8729	1700	4600	170.6	159.1

resulted in a gain of -42.6%. It is highly probable that the program crashed during the closed loop observation as there was a bug present causing the program to crash occasionally. The bug was fixed and poses no further problems. During the open loop test of set #10, TELCO lost the star and it was not focused on the slit for approximately 20-30 seconds, resulting in lots of lost photons. Because these are not fair tests of the comparison between open and closed loop operation, these tests will be removed from the data for the purpose of a fair statistical analysis. The program should not crash now that the bug is fixed, but TELCO frequently loses stars, resulting in another problem that tip/tilt will compensate for.

The mean value, x, and the sample standard deviation, S, of the theoretical throughput increase for the remaining eight samples, with ideal optics, were found to be

$$x = 81.3\% \tag{40}$$

and,

$$S = 50.5\%. \tag{41}$$

Using a t-chart, it was possible to determine a $(1-\alpha)$ confidence interval on the mean as

$$x - t_{\alpha/2,n-1}S/n^{1/2} \leq \mu \leq x + t_{\alpha/2,n-1}S/n^{1/2}. \tag{42}$$

For a confidence level of 99%, a t-chart yields

$$t_{\alpha/2,n-1} = t_{0.005,9} = 3.25. \tag{43}$$

Plugging into (42), the resultant 99% confidence interval on the population mean μ is found as

$$23.2\% \leq \mu \leq 139.4\%. \tag{44}$$

With ideal optical coatings we can be 99% confidant that the average increase in throughput with tip/tilt in operation will be in the above interval, resulting in a net gain. The cause of the large confidence interval is the small number of samples used and the large sample standard deviation. The number of samples was restricted by the amount of valuable telescope time which could be dedicated to these tests. Increasing the number of test samples would dramatically reduce the size of the confidence interval. The large standard deviation is the result of a large variance, caused by testing in a large range of seeing conditions. During good seeing the gain was very small, while tests performed during bad seeing conditions resulted in larger throughput gains as expected.

Effect of Tip/Tilt on Other Data Characteristics

The spectra from the closed loop tests were compared with actual spectra obtained the same night for the SFSU Planet Search Project. The two results important to the SFSU group are the S value and the resultant radial velocities determined from the spectra. The S value is a measure of the emission in the Calcium infrared triplet lines and is used as an indicator of the chromospheric activity in the star being observed. The radial velocities are measured from the resultant Doppler shift calculated from the spectra. Each of these values were constant for spectra obtained with and without tip/tilt, proving that the introduction of the tip/tilt optics have no adverse effect on the resultant data.

Probability of Catastrophic Failures

The result of test set #7 showed that the probability of catastrophic failure is also a factor to consider. Should TELCO lose the star during an observation, many photons are lost. When the star is off the slit for too long, the observation must be restarted resulting in time losses of up to 20 minutes. The number of times this occurs can be estimated at about one in fifty, so the probability of catastrophic failure without tip/tilt in place is approximately 1/50, or

$$P(F_{no\ t/t}) \cong 0.02\ . \qquad (45)$$

For tip/tilt to lose the star the image would have to jerk outside of the PMT surface at speed exceeding the capabilities of tip/tilt. From the observed behavior of observations during open loop operation, this is high unlikely. From the data to date on tip/tilt performance, this situation has no occurred. The tip/tilt system has been used for a total of 21 observations with no catastrophic failures, so the probability of catastrophic failure with tip/tilt in place is approximately 0/21 with the data to date, or

$$P(F_{t/t})_{to\ date} \cong 0. \qquad (46)$$

In addition to the above tests, tip/tilt was used, with the current test optical coatings to get actual data to be used for the SFSU planet search project. In these observations, seeing was so bad that the resultant SNR was far below

workable levels without tip/tilt. Employing the tip/tilt system resulted in workable SNR levels allowing the astronomer to continue observing and obtain acceptable data. Again the S values and radial velocities were as expected.

Expected Improvements

All tip/tilt observations were performed without TELCO communication and without the controller automatically selecting the proper output range for the PMT preamplifiers. Without communicating with TELCO, some light was probably lost at the collimator resulting in less measured throughput gain. Running at a constant PMT preamplifier range causes the data acquisition board to see more noise than necessary, resulting in less than optimal corrections for the dimmer stars. The installation of the TELCO communications and the dynamic PMT preamplifier gain will result in an even better throughput gain than has been seen to date.