Short and Long Term Variability Analysis of High Mass X-ray Binary System BD+53 2262

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ABSTRACT

The star BD+53 2262 is an emission line star that has been hypothesized to be a High Mass X-ray Binary system (HMXB). The only time this star has been looked at in the X-ray wavelength, it was below detection levels. The purpose of this thesis is to see if there is any variability in the visible wavelengths to suggest that this is indeed a HMXB system. After 4 years of observation, BD+53 2262 shows a 1/10th decrease in magnitude and some small variations within each observation year. This long-term variation is small but consistent with a super orbital period that the star may be exhibiting.

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Chapter 1

Introduction and Background

1.1 High Mass X-ray Binary Systems

High mass X-ray binary systems (HMXBs) consist of a giant O or B spectral type star and a compact object, mainly a neutron star. These two stars orbit each other in a highly elliptical manner and emit X-ray radiation. The high mass part of the binary system's name comes from optical companion. For most HMXBs the optical companion of the system is also spinning quite rapidly. For reasons yet to be discovered, B spectral type stars are the fastest rotators out of all stars (Charles & Seward 1995). Because of this, B type stars tend to have an equatorial disk that causes emission lines in the optical spectrum. The B type stars that show emission lines in their spectra are classified as B*e* stars. Through observations, it has been seen that there is a period where the emission lines in the spectra no longer appear for a while and then re-appear, this is known as the Be phenomena (Lamers et al. 1998) and is thought to be present in most B*e* stars and HMXB systems.

The X-ray signatures on these systems comes from the interactions of the star with the neutron star. Both stars exchange matter and form an accretion disk around the neutron star, while interacting with the equatorial disk around the star. The release of gravitational potential energy causes the X-ray radiation that is observable from this system. There are however, periods where the accretion disk fades and there is no detectable X-ray signature from the system, but as the star begins to replenish the accretion disk, X-ray signatures become detectable once more. This makes the analysis of HMXB's difficult because the neutron star orbiting the system could not be detected if there is no disk or material for the compact object to interact with. Because of this, a HMXB system could be X-ray silent for several years.

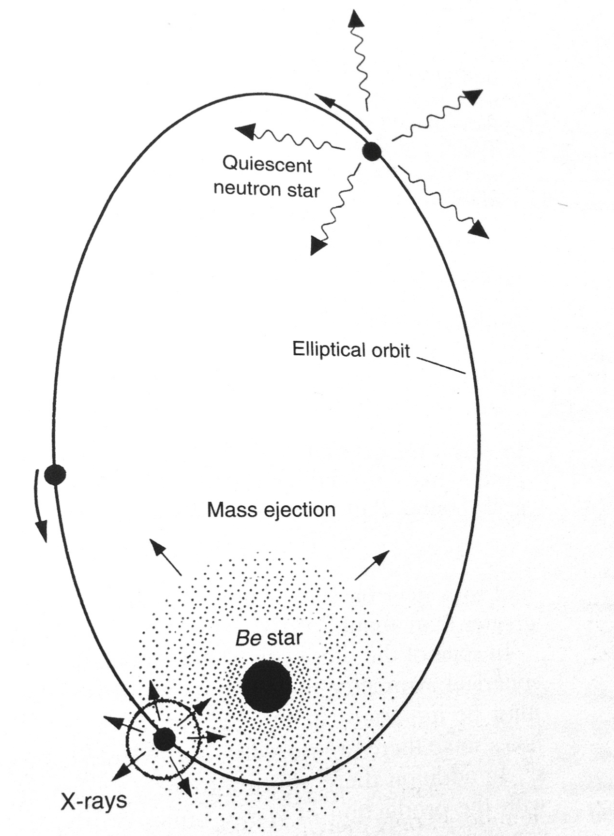


Figure 1.1 A diagram of a HMXB System (Charles & Seward 1995)

There is also the possibility that as the mass transfer rate declines on to the neutron star, the neutron star itself could be building a centrifugal barrier that cannot be crossed if the mass accretion rage dropped below a certain level. This would happen because of a reduction in pressure on the magnetosphere of the neutron star that allows it to expand. From there, this star could reach the point where the accretion material that enters the magnetosphere would be greater than the orbital speed of the neutron star and the material would be flung off by centrifugal forces instead of accreting on to the neutron star. This would cause an abrupt stop in X-ray radiation and would make the whole system X-ray quiet (Charles & Seward 1995). For more detail, see figure 1.2. If an observation or a survey in the X-ray is done during this time,

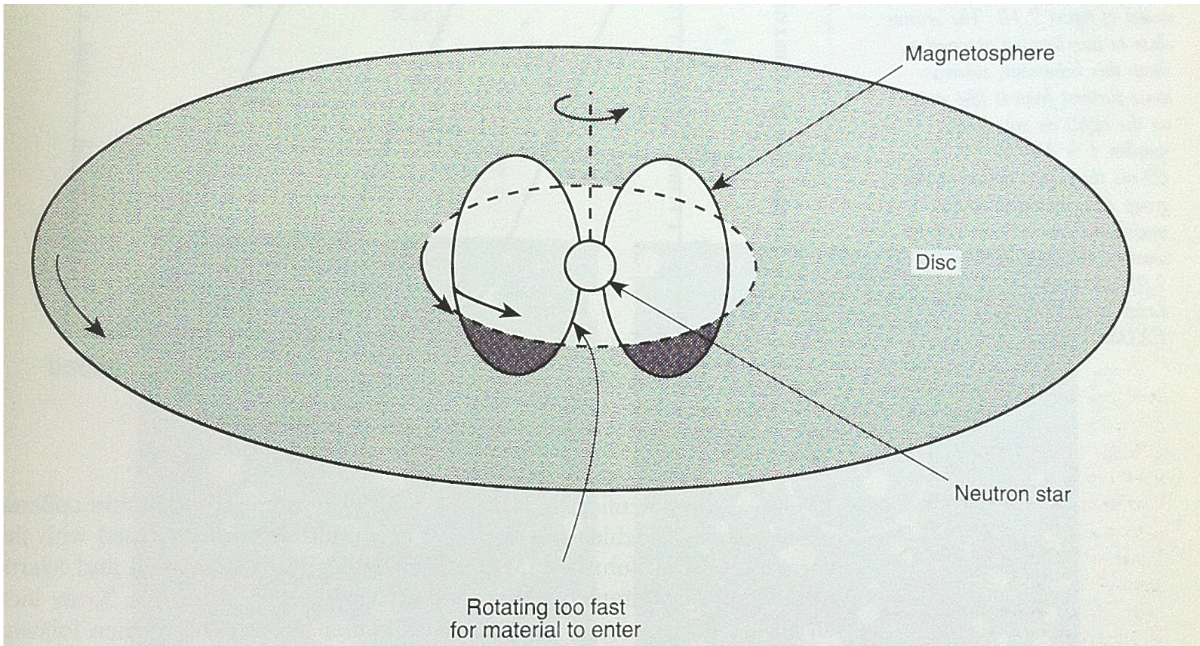


Figure 1.2 The Centrifugal Barrier created by a Neutron Star. (Charles & Seward 1995)

that HMXB will not be detected. Also because of binary system's nature, most orbits are highly elliptical, which adds to the difficulty of detecting HMXBs. This had led to discovering many HMXBs with unique properties that are becoming as abundant as the systems being discovered.

1.2 System BD+53 2262

BD+53 2262 is classified as an emission line star. The spectral type of this star is a B5 and has a published magnitude of 10 in V in Helfand, et al.(2001). This star was first noted for its bright hα line (Merrillet al., 1950). However, it hasn't been observed in the optical since. This star appears in the Liu 2000 catalog of high mass X-ray binaries. BD+53 2262 was also studied in a BeppoSax survey for Be X-ray candidates in 2001. J.M Torrejón and A. Orr surveyed five HMXB candidates provided by a previous study. Unfortunately, BD+53 2262 was below the BeppoSax range and therefore was seen as being X-ray quiet. The another identifier for this star, called 1H 1936+541, is about 0h5m2s +0°20' away and is the proposed X-ray companion to BD

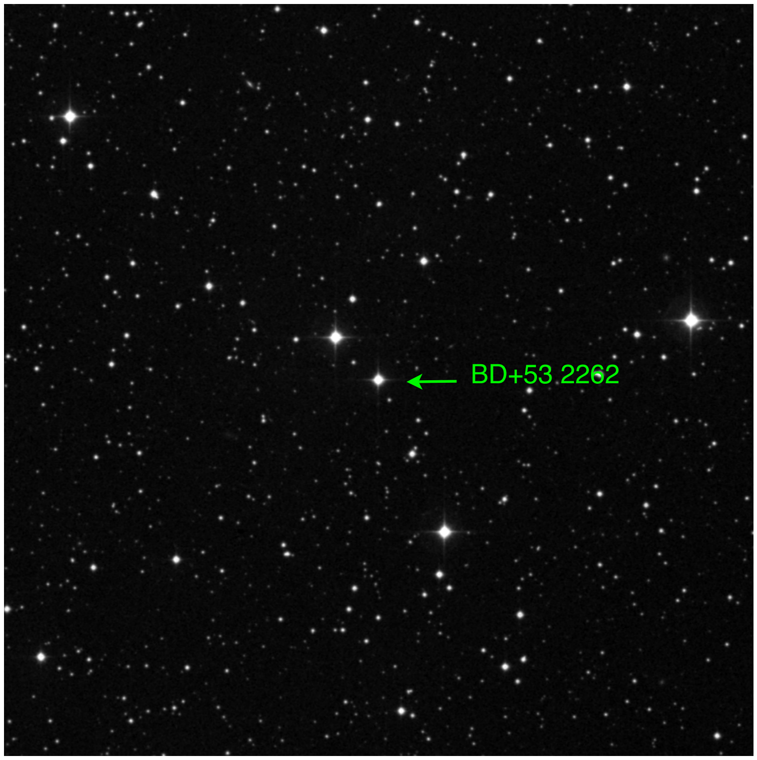


Figure 1.3 The Starfield of BD+53 2262. (Digitized Sky Survey)

+53 2262. Torrejón and Orr found that during this survey it was completely absent in one X-ray band but barely below the detection level in another X-ray band. This has led Torrejón and Orr to believe that BD+53 2262 could still be a HMXB but in its quiescent state. Simbad, an astronomical database, labels this identifier as an X-ray source only. There aren't any papers that directly state that BD+53 2262 and 1H 1936+541 are an HMXB system. However, their proximity and the spectroscopic nature of BD+53 2262 would indicate that this is most likely a HMXB system. As far as manual scans of that area, There is a radio source within a 30' window of BD+53 2262 that has only been identified as a radio source and nothing else.

1.3 The Project

The purpose of this paper is to view and discuss the optical properties of BD+53 2262 and see if there is some potential short or long term variability from 2007 to 2011. This will be achieved by analyzing optical light curves gathered from 2007 to 2011. By studying the optical light curves, we can gain information about the star's behavior in the optical, the stars interaction with the compact object and see if there are any forms of variability, short or long term, in BD +53 2262 that would indicate that it is a HMXB system.

According to A. Rajoelimanana, there are long term variations can actually be superorbital modulations that can expand from hundreds of days to years. The author believes that this modulation can be caused by the formation and depletion of the equatorial disk around the optical companion (the Be phenomena) and can be seen in the optical wavelengths. If detected, this would be a wonderful explanation for any long term variability found over the years that this data was gathered.

Chapter 2

Observations and Analysis

2.1 Observations

The primary telescope used for our observations is the David Derrick telescope in the Orson Pratt Observatory. The David Derrick telescope is a 16” reflecting telescope with the ability to switch between two different focuses: Cassegrain and Newtonian. Both of these focuses were used in the data gathering process. The Newtonian focus was used in 2007-2008 and the Cassegrain focus was used from 2010-2011. There was also a switch in CCDs during the observations done on this project.

The Newtonian telescope has a focal ratio of *f*/4 and the CCD, an ST-10, had a plate scale of .0864”/pixel. The field of view was 31’ by 21’ and the temperature averaged at about -10 degrees Celsius over the summers of 2007-2008.

Table 2.1 CCD Information for Data Taken on BD+53 2262

CCD	Telescope Focus	Focal Ratio	Plate Scale (arcsec/pixel or mm)	Field of View (arcmin x arcmin)	Years Used
STL-1001	Cassegrain	f /12.5	40.64 mm	17x17	2010-2011
ST-10	Newtonian	f /4	0.0864 pixel	31 x 21	2007-2008

Figure 2.1 The Orson Pratt Observatory

The Cassegrain telescope has a focal length of 5075 mm and a plate scale of 40.64 arcsec/mm.The CCD attached to the telescope is the ST-1001 that has a field of view of 17’ by 17’ and an average temperature of -10 degrees Celsius over the summers of 2010-2011.
The data from 2007-2008 was taken in the Johnson V filter with the occasional night in the R filter. Because there is much little R filter data, it will not be included in this paper. When the new CCD was installed, there was also replacements made with the filters. The telescope acquired four new Johnson filters B,V,R, and I. From 2010-2011 most of the data was gathered in the B,V and I filters. We were particularly interested in the I filter because it is a near infrared filter and would hopefully allow us to see the equatorial disk around BD+53 2262.

Because the data was gathered with two different CCDs, a challenge for the observers was to center the field of view around BD+53 2262 in a way that would allow nearby stars to be used as comparison stars for the reduction and analysis process. Also since this is a student run

Figure 2.2 The David Derrick Telescope

telescope, There had to be an understanding between observers about how the star was centered in the CCD images.

2.2 Reduction

Reductions were done using basic IRAF procedures. Using the package ASTUTIL the headers were able to be changed and have information added to them such as the the filter, the name of the star and where to find the date and time. After the headers were updated, the images were ready for the reduction process.

The reductions that take place in IRAF include subtracting and dividing out calibration frames called zero or bias, darks and flat frames. The process generally takes a raw data image and will subtract the bias frame, subtract the dark frame and divide out the flat frame.

The bias frames are images of no exposure length that account for the noise when the camera is initially turned on. This shows us the initial scattering of the chip and lets us remove this scatter from the final image frames.

The dark frames account for the temperature differences and gradients in the cooling of the chip. The exposure time for the dark frames is close if not the same to the exposure time of the images and therefore account for the dark current in the image.

The last calibration frame is the flat frame. This provides us with a way to correct for the dust and disfigurations on the mirrors. Flat frames are usually taken at twilight or just before sunrise when a nice “flat” sky can be observed with minimal gradients from the sunrise or sunset.

The reduction process gives the data a cleaner appearance and removes a lot of error that can come from the camera, the sky and the telescope. There were several nights in the data that didn’t have either dark or flat frames for that specific night. For those nights, the closest observations calibration frames would be used to reduce those images.

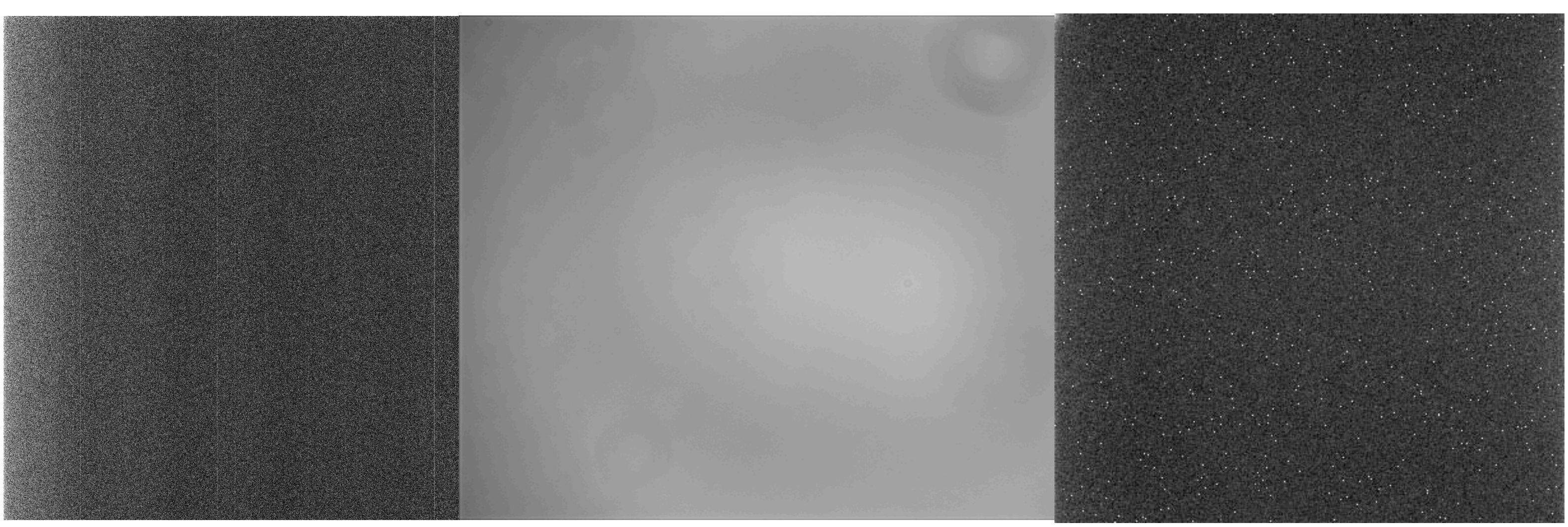


Figure 2.3 Sample Bias (or Zero), Flat, and Dark Frames

2.3 Analysis

After the images are reduced, the PHOT-ing process begins. The PHOT-ing process involves picking comparison stars and gathering their instrumental magnitude, or the magnitude read directly off of the CCD image. One tricky thing about switching CCDs in between years of observations is the change in the field of view. In 2007 there was a 21' by 31' field that shrunk to 17' by 17' with the new CCD. One also has to account for imperfect centering of the images by the observers. Despite all of the changes, 26 comparison stars were found that were visible in all the data over the years and that were bright enough to be lost through semi-cloudy nights.

Instrumental magnitudes were obtained using a student written code called NIGHTPHOT 4. The purpose of NIGHTPHOT 4 is to maximize the aperture chosen for the object by analyzing each frame, preforming a PSF measure and determining an average full width half max measurement of the target and its surrounding comparison stars. The maximization of the aperture maximizes the ratio of background noise to the light of the star. This can also help us reduce the effects of bad (semi cloudy) observation nights that wouldn't be useable otherwise.

Differential magnitudes were acquired using VARSTAR 5, an external package that gives differential magnitudes and reduces error by elimination of comparison stars. It also measures the magnitude by flux so the brighter stars have more influence on the whole ensemble of stars. VARSTAR 5 then outputs differential magnitudes based on the average magnitude of the stars that had the least amount of variation (had the lowest amount of error). Out of the 26 comparison stars used in the PHOT-ing process, only 7 were used in the final comparison to obtain differential magnitudes of BD+53 2262.

For the error analysis, a star of similar magnitude was chosen. Since that star was assumed not to be a variable star, the errors from this star should be low and consistent across all 4 four years that observations were made. It also could not be brighter than BD+52 2262 because of the possibility of saturation of the image during observations. The closest comparison star that was found in the ensemble is called star 2 and is shown in figure 2.4. The magnitudes of these two stars differ by 2.1 magnitudes and this star is found in every single image frame used. By finding the error per observation or the standard deviation of star 2, an error range can be produced that will account for all errors except for the variability that we hope to see in BD+53 2262 .

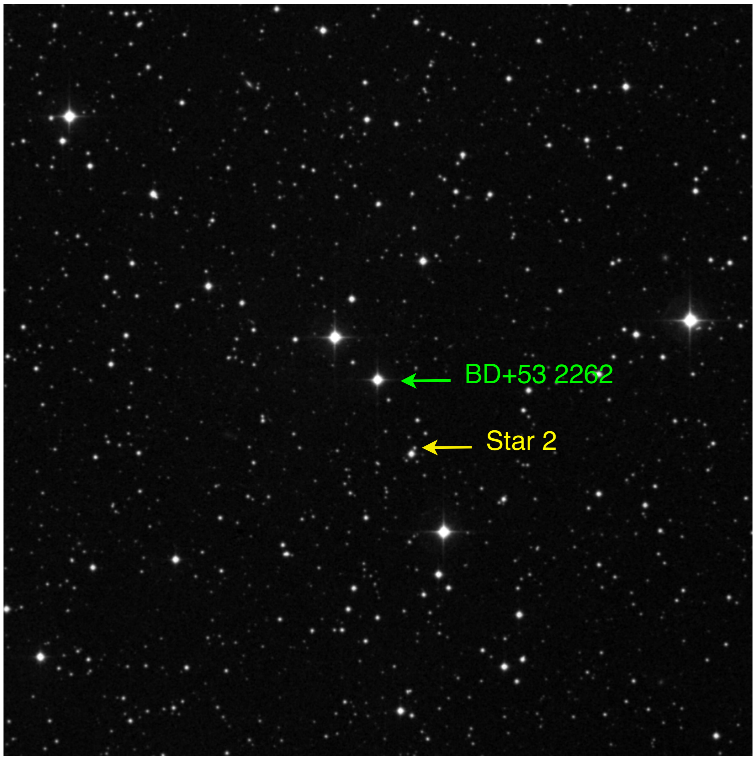


Figure 2.4 The Starfield of BD+53 2262 with Star 2

Chapter 3

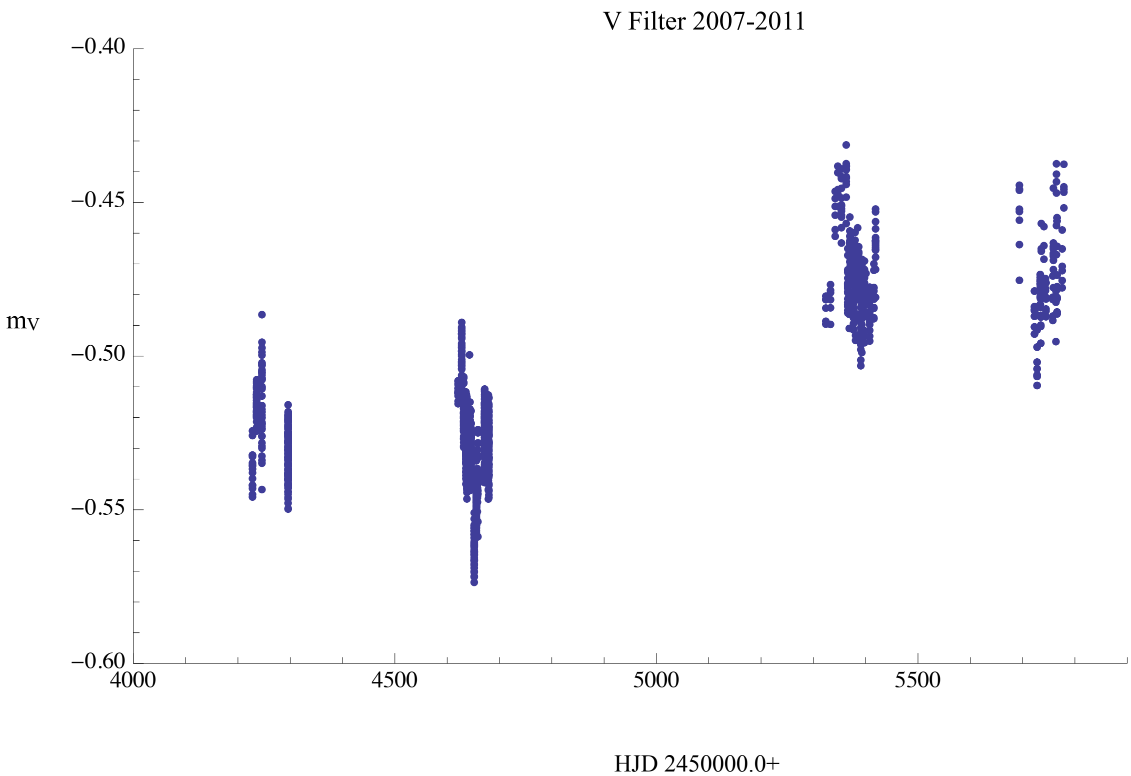
Photometric Results

3.1 Raw Photometric Data

The first method that was used to look at the data was just plotting every single frame of data that we had. This showed us the nightly spread in each observation and any initial forms of variability. The plot that catches the most attention is Figure 3.1. This plot shows the differential magnitude of BD+53 2262 in the V filter over four years and there is definitely a decrease in luminosity over those four years. There is also potential visible changes in magnitudes within each year. Overall it seems that there is at least some variability being exhibited by the system in the V filter.

The B filter also showed a fair amount of variation from the raw data. The most surprising was the decrease in magnitude from 2010 to 2011. There was only one night of observation done in the B filter in 2008 and it appears that BD+53 2262 had close to the same brightness then and was in an increased state in 2010 and then dropped again in 2011. A similar jump is seen in the I filter over this time period as well. It appears that the V filter does not show that same change in magnitude over the same timespan.

There were also some individual years that showed some interesting variations. One of these years is 2008 in the V filter. Within the raw data for 2008 it appears that there is a a consistent decrease in data that hits a maximum around HJD 4645. After that, it begins to increase a little and then seems to level out. This variation is within the span of one tenth of a magnitude but still has an interesting shape to it. There seems to be an increase over the observations in 2007 but it is varying within less than one tenth of a magnitude. During 2010, the B filter has a similar dip in magnitude that reached a maximum at HJD 5357 but then began to increase and level out as well. There is also a small increase at the end of that observation year (HJD 5420) but unfortunately, there was no more data gathered after that point. Somewhat oscillatory behavior can be seen in the plot of the 2010 data in the I filter. However, there seems to be quite a bit of spread throughout those observations and one must wonder if those small oscillations are small variations from BD+53 2262.



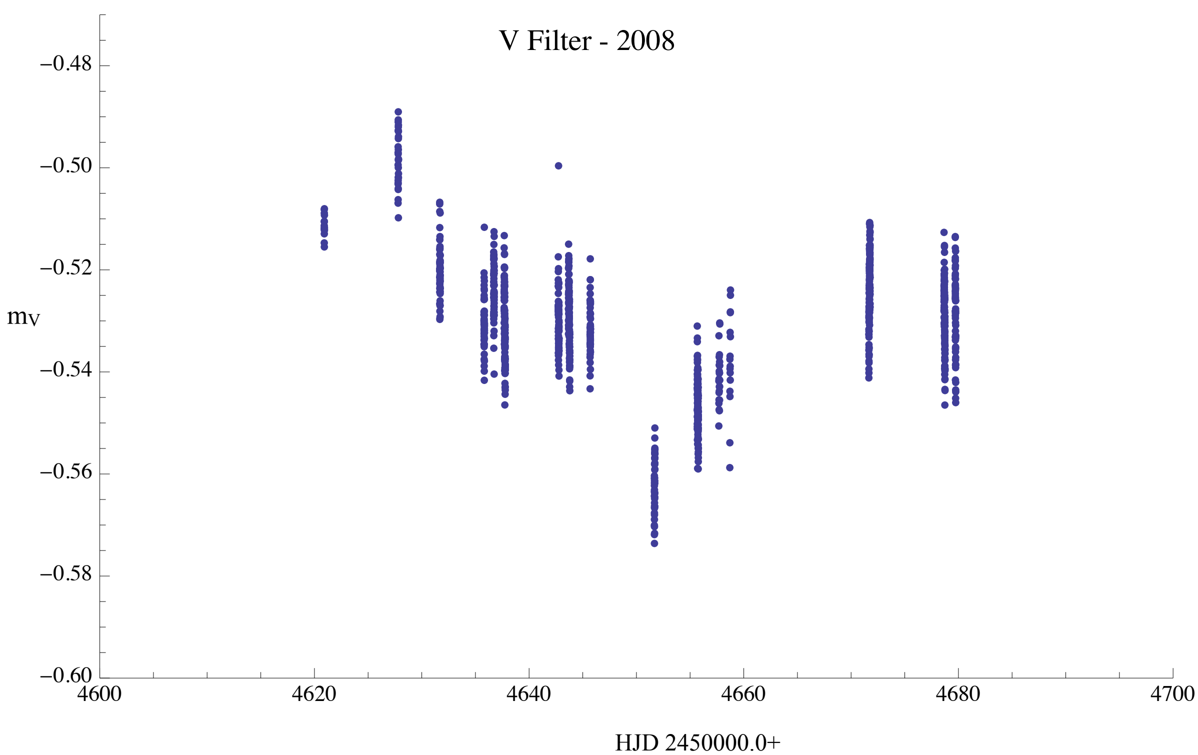
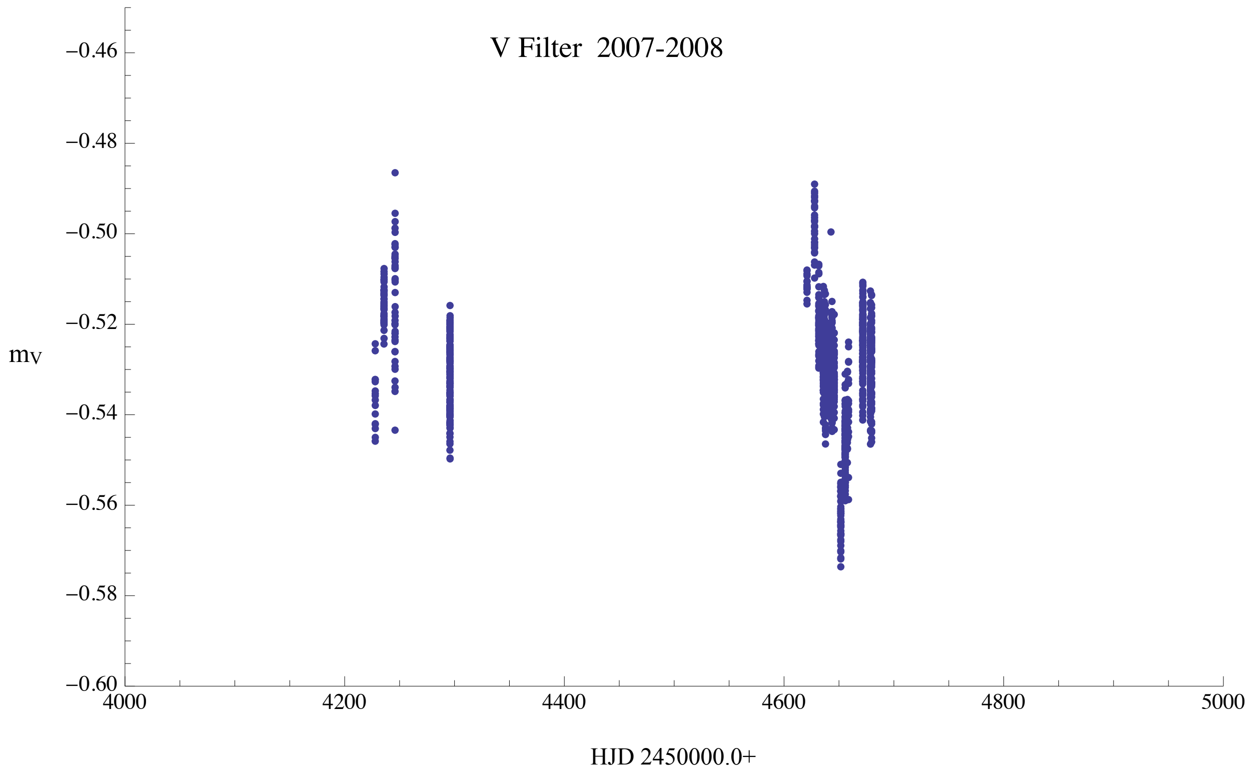


Figure 3.1 Raw Data in the V filter from 2007-2011 and 2008



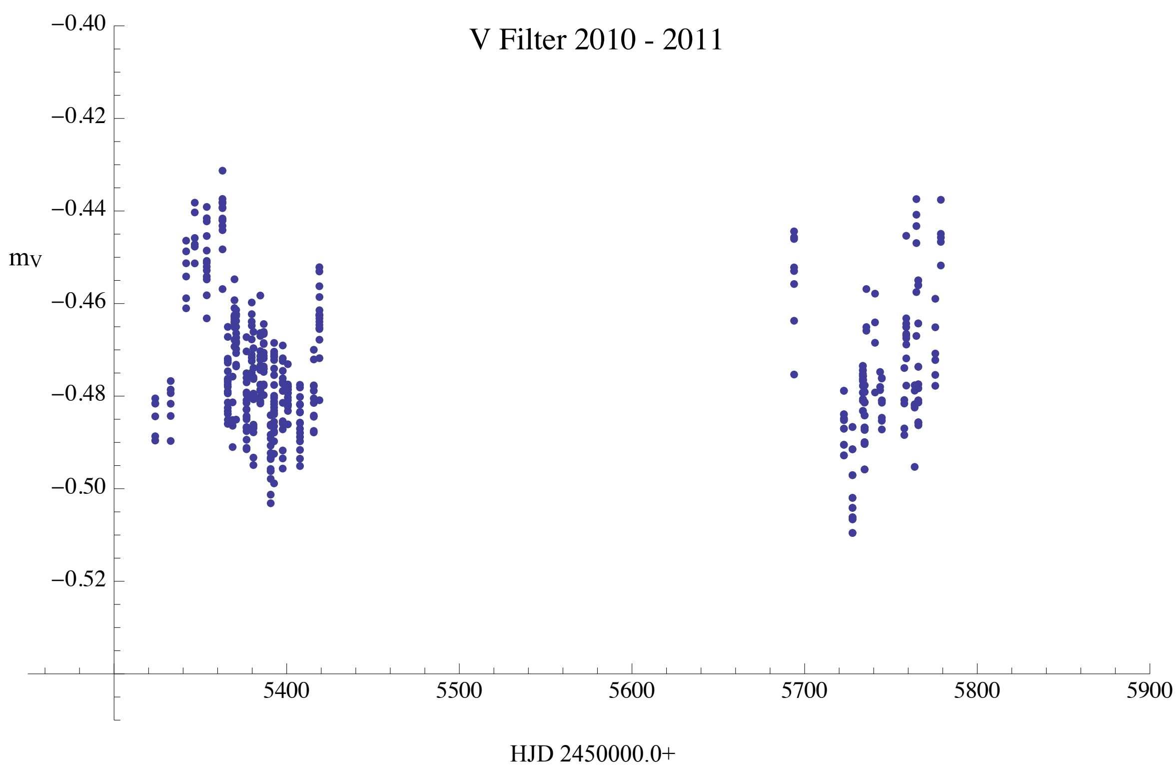
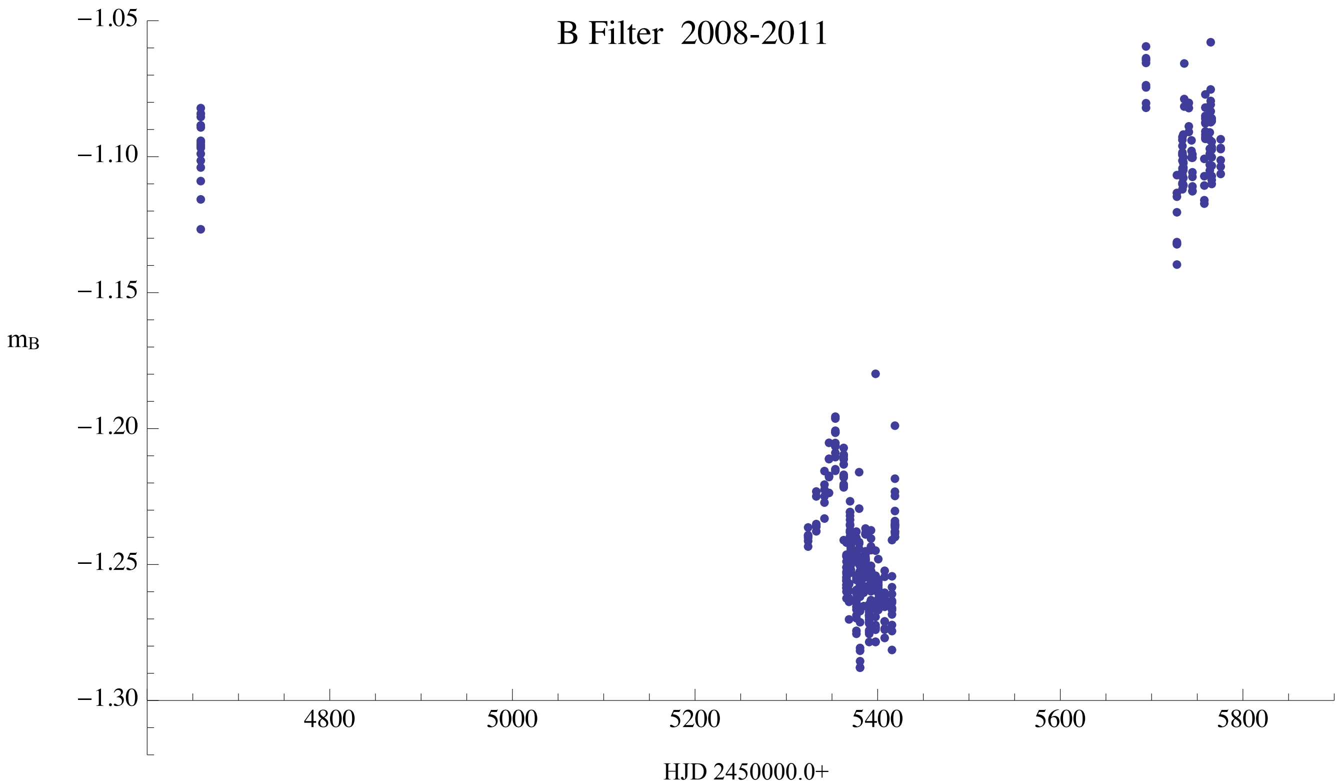


Figure 3.2 Raw Data in the V filter from 2007-2008 and 2010-2011



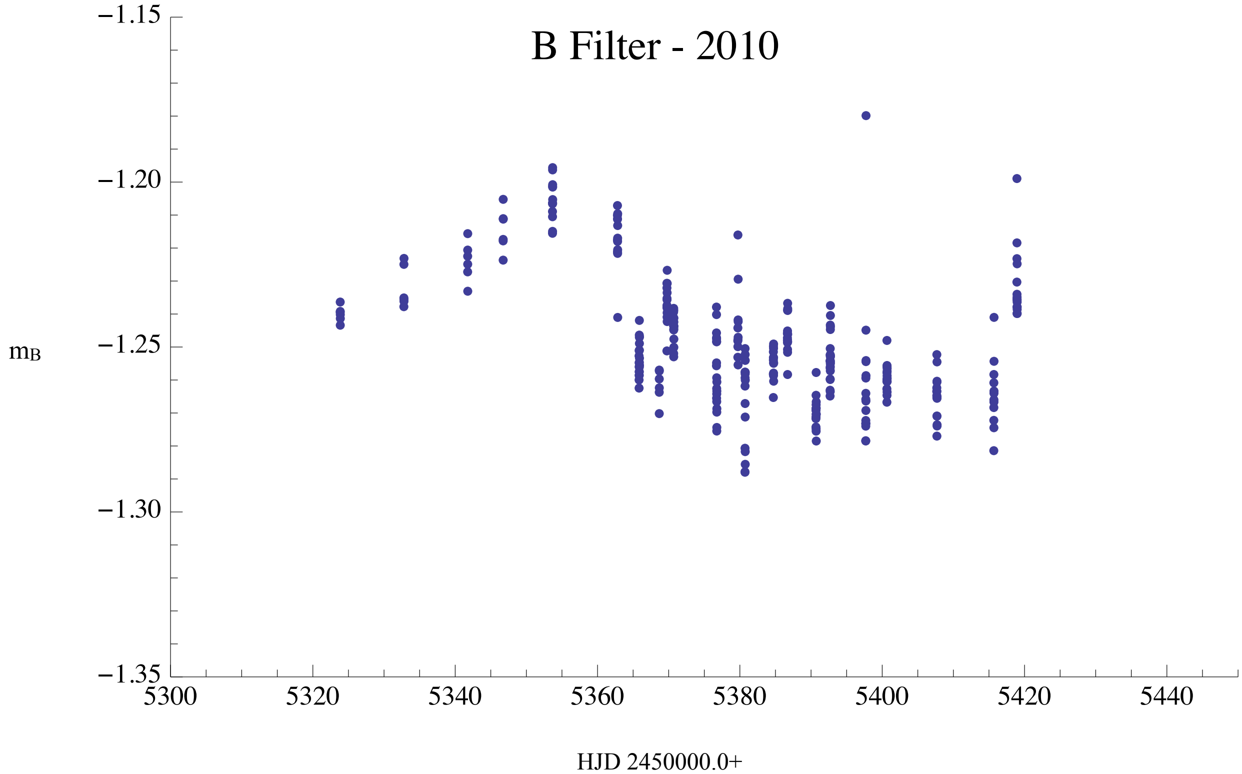
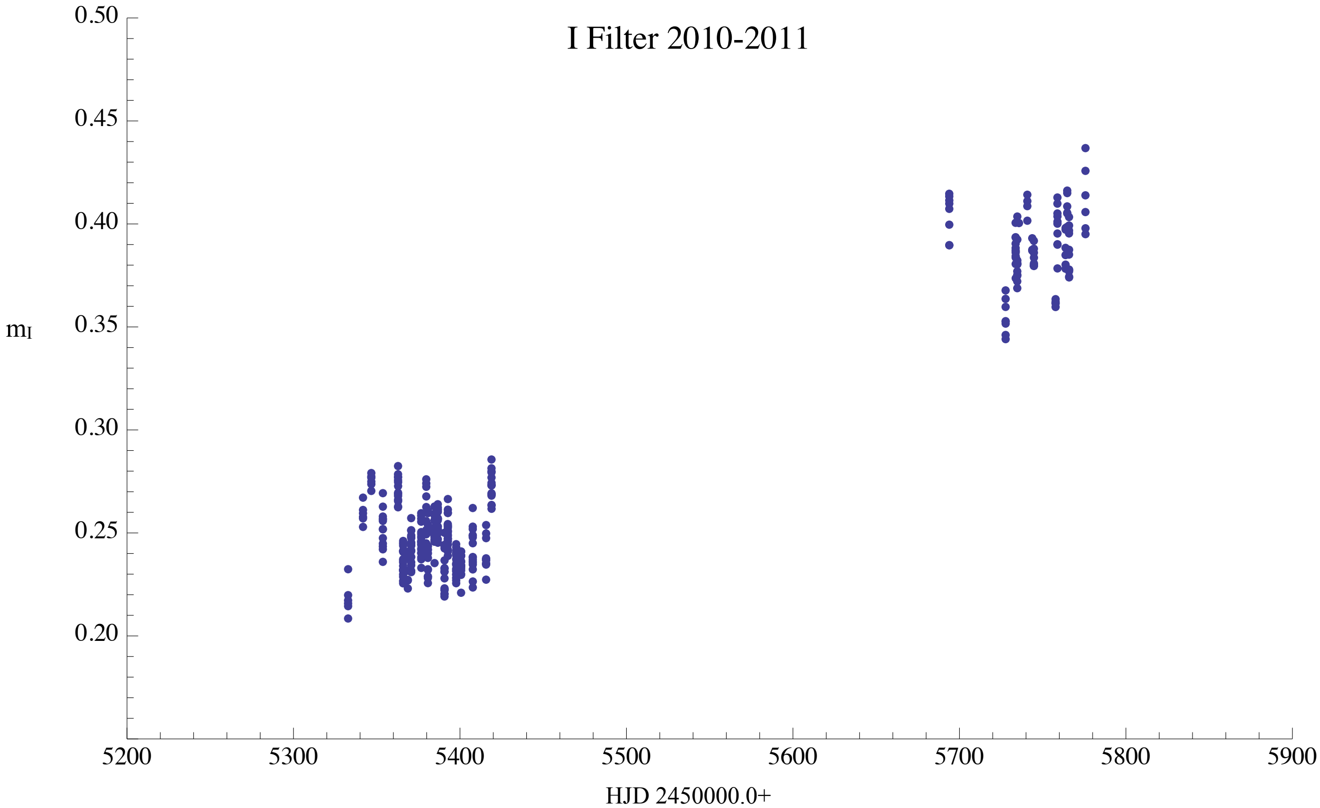


Figure 3.3 Raw Data in the B filter from 2008-2011 and 2010



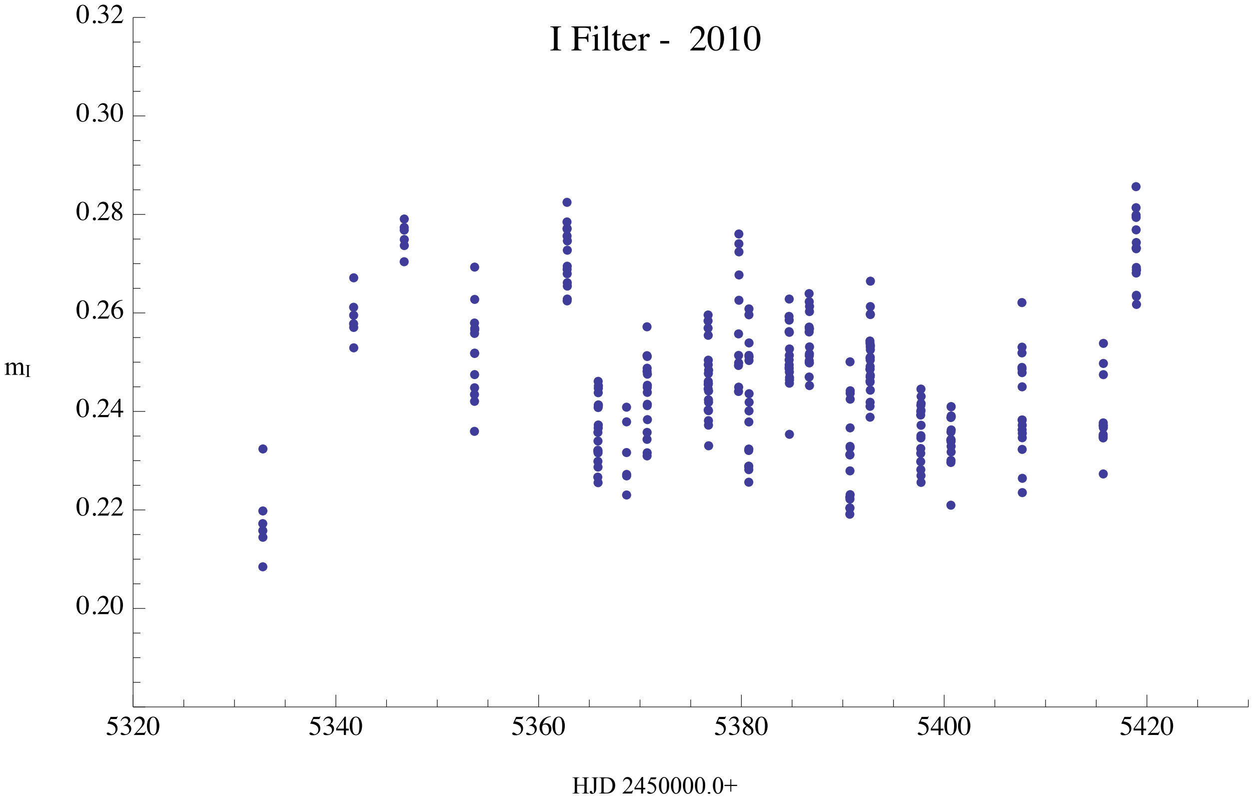


Figure 3.4 Raw Data in the I filter from 2010-2011 and 2010

3.2 Error Analysis Data

As far as the large four year variation seen in the V filter, it appears to be real. This decrease in luminosity in the V filter of about 0.095 of a magnitude is still visible after each night is averaged and error bars are put in place. The variations seen within 2008 in the V filter are still present and seems to be completely real as well. In 2010 there seems to be a small rise and drop in magnitude but it all roughly all fits between the error bars and in 2011 there is a general decreasing trend in magnitude.

The large variation seen from 208 to 2011 in the B filter are also well outside the range of the error bars and appear to be real. One must wonder why this star was brighter in the B filter in 2008 and not in the V filter during the same year.

There is a decrease in magnitude from 2010 to 2011 in the I filter that is quite definite as well. The oscillatory graph seen in 2010 in the I filter fits within the error bars and could just be noise. the 2011 plot for the I filter shows a general decreasing tend in magnitude as well.

Table 3.1 Average Error per Observation for BD+53 2262

Year	Filter	Error per Observation
2007	V	0.00628792
2008	B	0.00854864
	V	0.00618055
2010	B	0.0171908
	V	0.0163668
	I	0.01708673
2011	B	0.01157076
	V	0.00854864
	I	0.01105632

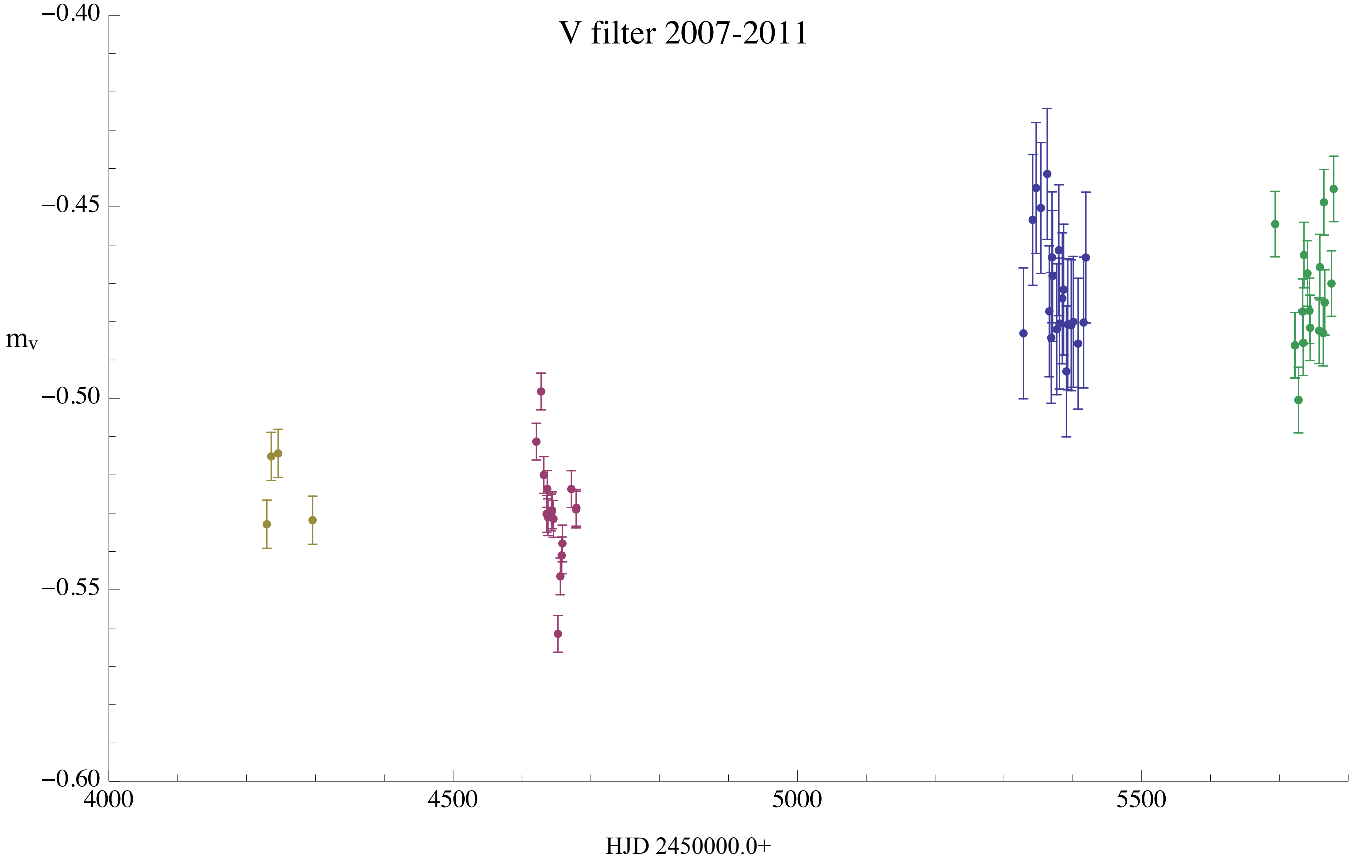


Figure 3.5 Analyzed Data in the V filter from 2007 - 2011

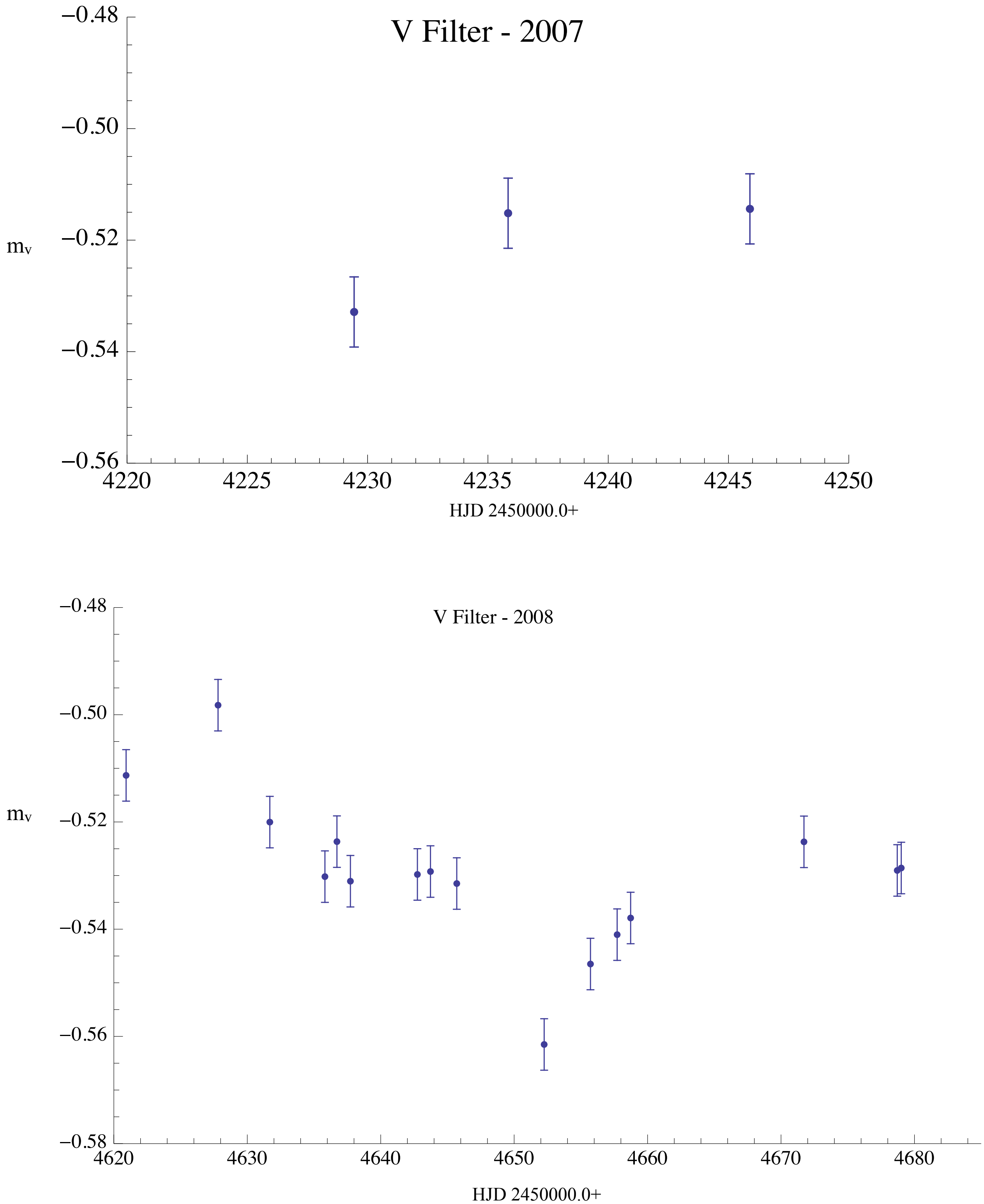
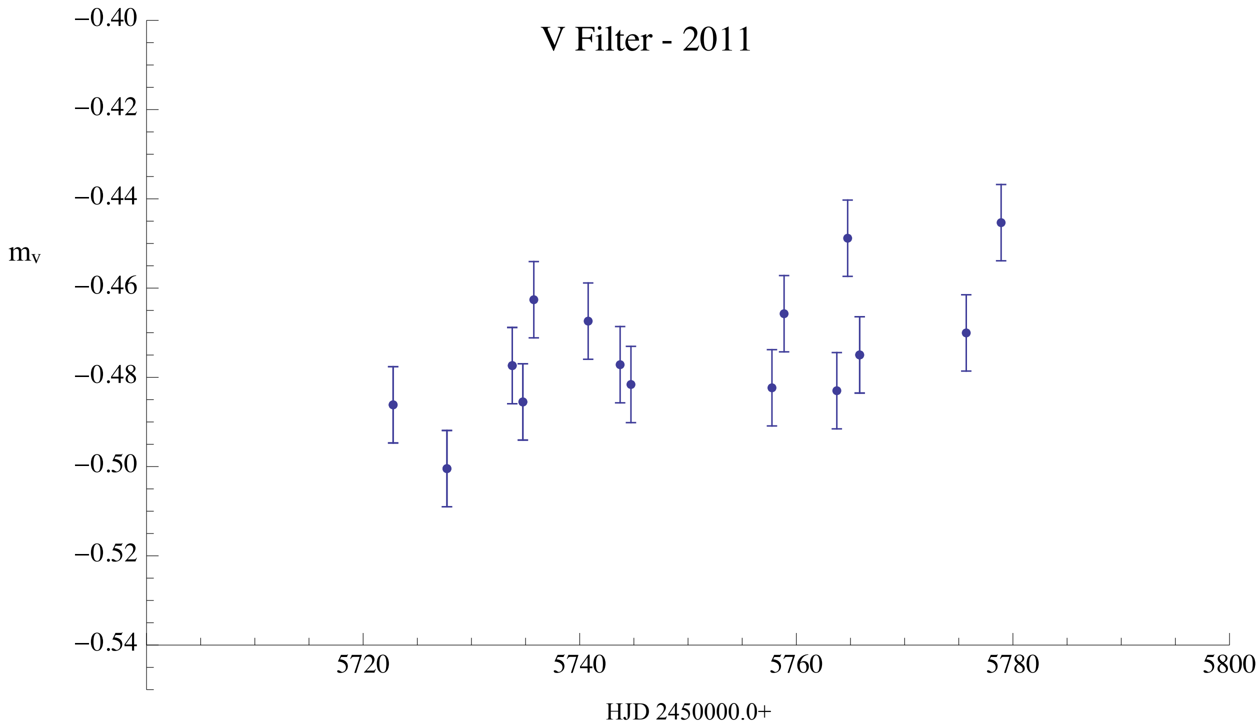


Figure 3.6 Analyzed Data in the V filter for 2007 and 2008



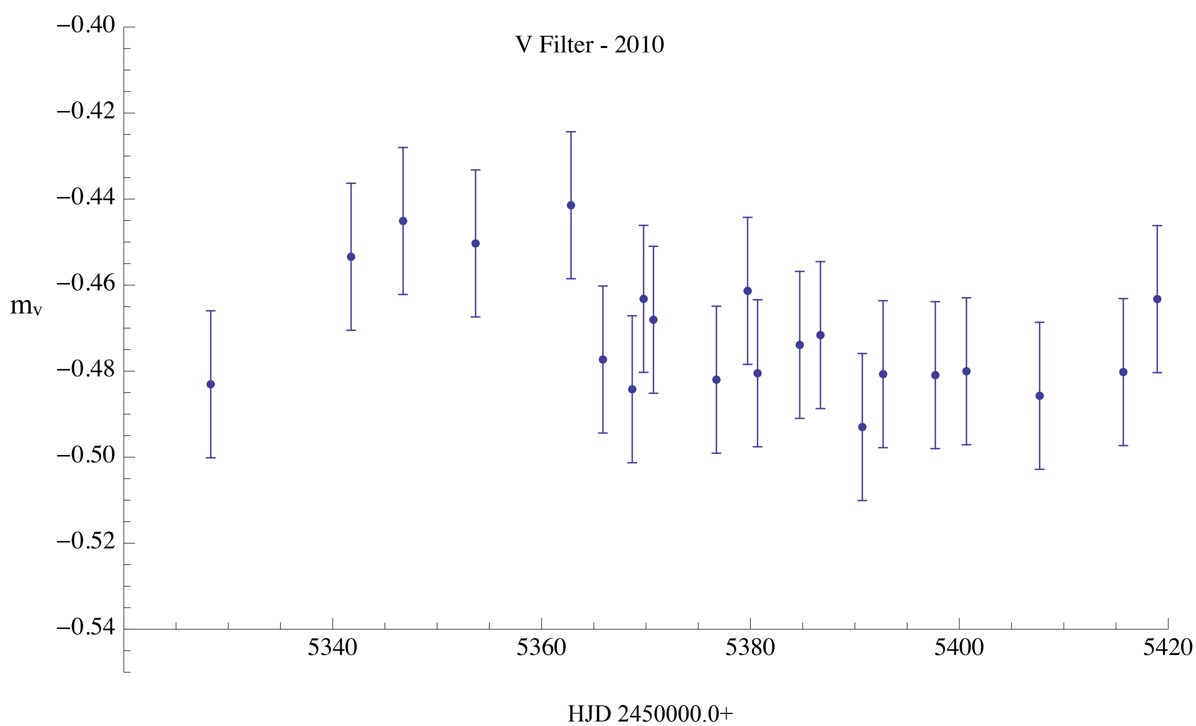
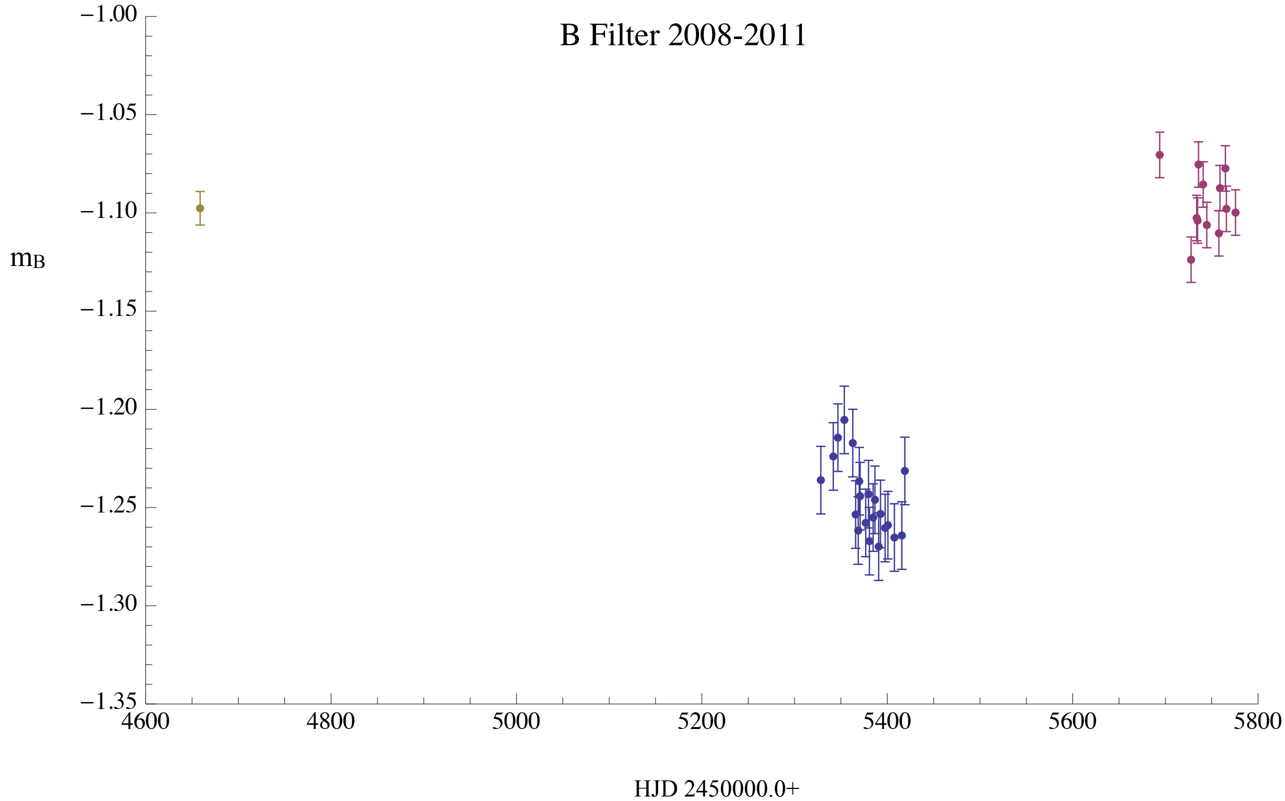


Figure 3.7 Analyzed Data in the V filter for 2010 and 2011



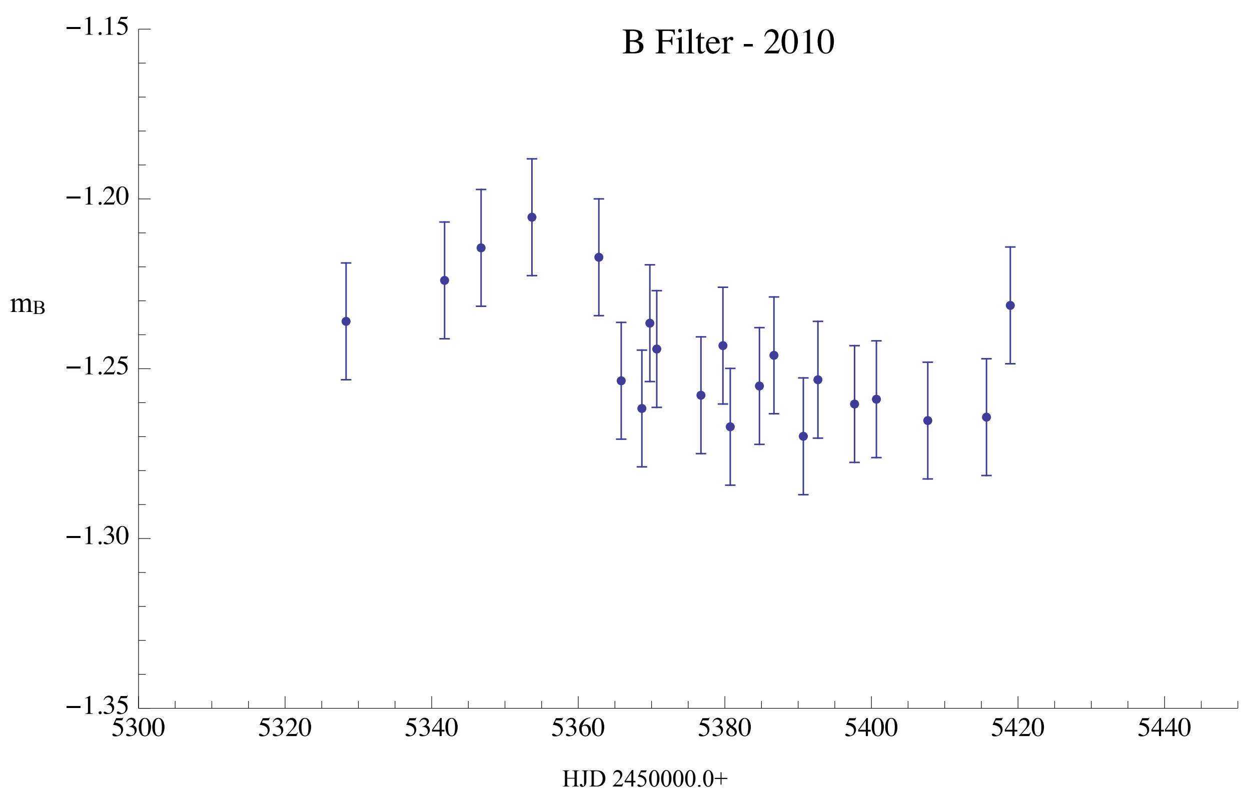


Figure 3.8 Analyzed Data in the B filter for 2008-2011 and 2010

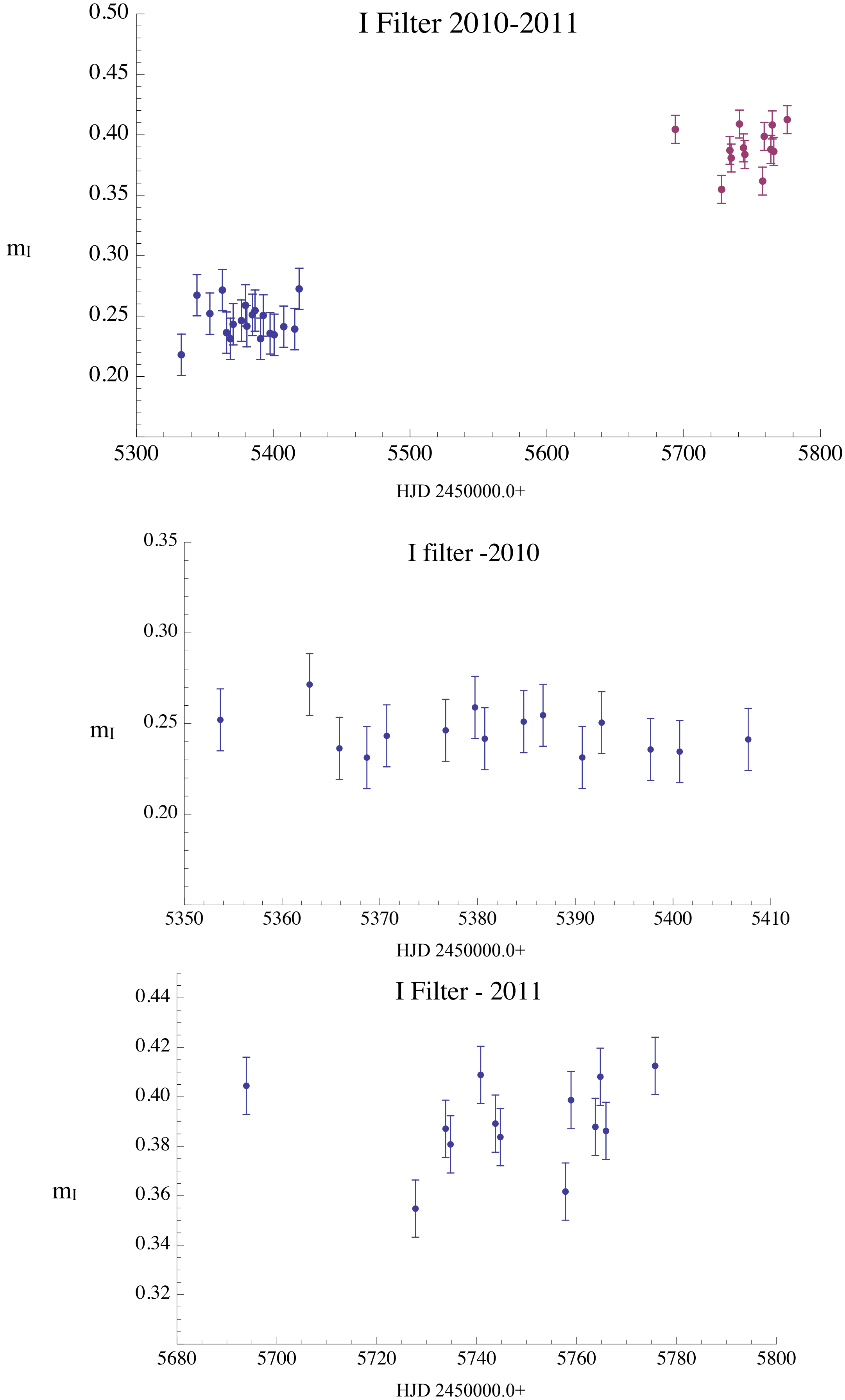


Figure 3.9 Analyzed Data in the I filter for 2010-2011, 2010, and 2011

Chapter 4

Discussion

4.1 Short Term Variability

There has only been really one form of evidence for short term variation. This comes from the data in 2008 for the V filter. In this case we see that increase in magnitude (about 1/50 of a magnitude) and we see it drop again. Since we only have data in the V filter for this year that makes it a bit more difficult to say what might have caused it but it could have been a small clearing of dust around the star. It could also be explained by a tiny X-ray flare up that increased the brightness of the whole system. However, there is no real way to check that without digging through archive data and hoping to match the dates. Any other small variations seen within the other filters and years could be of a similar cause but less drastic than this event in 2008. Despite this, there seems to be no real evidence of short term variation in this system.

4.2 Long Term Variability

There seems to be long term variability as seen in the four year plot in the B and V filters. It is not large but it is definitely there. This could be explained by several things, the first is the star could be re-stocking on its equatorial disk which brings in more dust and could cause the magnitude to decrease. Another could be the system's inclination towards earth. This could cause a small form of variability as well. The last and potentially least probable is that this could be the system going in to a quiescent state. The down side to this is that the star would most likely not emit any X-ray for some amount of time and will not be detected. Since we have (if this is an entry to a quiescent state) at most half of a period for this star, we will not be able to get a good approximation of the systems superorbital modulations. We might have to do what A. Rajoelimanana and his fellow researchers did and track this star for 16 years. Some of Rajoelimanana's data showed maybe 1.5 periods or 3 over the span of 16 years. The optical variations seen in BD+53 2262, even though there was not much of it, still appears to be consistent with a HMXB system.

Chapter 5

Conclusion

5.1 Variability

The purpose of this project was to explore and find forms of variability of BD+53 2262 to see if it should be classified as an HMXB system. There was no real evidence of short term variations outside of 2008 in the V filter. This shows that 2008 might have just been an anomaly within the data or that the star had a small increase that could have been a gap in the equatorial disk or some form of increasing magnitude. This could potentially be a tiny X-ray flare but without simultaneous X-ray data, there is no way to confirm this statement. Long term variability looks much more promising for this star and as mentioned in the discussion section above, this could possibly be the system entering a quiescent state and be exhibiting superorbital modulations. This is by far the most exciting of the possibilities and would support a classification of this star as a HMXB system.

5.2 Further Work

The next step that should be taken from here (besides a much more rigorous error analysis) is periodicity analysis. For this particular system some good options would be using a Phase Dispersion Minimization technique or a Lomb-Scargle treatment as both of those are good for unevenly spaced data. I believe that there might be a form of periodicity found within the four years of observation and would hopefully be statistically significant. Some preliminary periodicity attempts have been made but were not included because there was no statistics done on the attempts and it was unclear whether the period came from the star or the spacing of our data. The most popular period results were 3 hours (the length of the average observation run), about four months (the length of the months we observed for) and five years (the time span of all of our data).

Ideally, it would be nice to get a long baseline of observations for this object, long meaning about 10 years, with at least one peek in the X-rays each year. In order to find any forms of periodicity and variability, a multi-wavelength analysis would be best. It would also be nice to look in the Radio wavelengths since there is a nearby radio object and pulsars are detected through those wavelengths as well.

Bibliography

Apparao, Krishna M.V., 1994 ,SSR, 69, 255A

Belczynski, Krzysztof & Ziolkowski, Janusz, 2009, ApJ,707, 870B

Charles, P. A. & Seward F. D., 1995, “Exploring the X-ray Universe” (Cambridge University Press)

Helfand D., Moran E., ApJ, 554, 27

Lamers, H.J.L.M., Granz-Josef Zickgraf, Winter D. Houziaux (1998) A and A 340,117

Merrill P.W., Burwell C.G. 1950 ApJ 112,72

Merrill P.W., Burwell C.G. 1942, ApJ 96,15

Rajoelimanana A. F., Charles P.A. and Udalski 2010, A. Mon. Not. R. Astron. Soc. 1, 26

Reed B.C Astron. J 125,2531

Torrejon, M.J. Orr, 2001 A., A & A ,337 ,148T

Tuohy I. R., Buckley D. A. H., Remillard R. A., Bradt H. V., Schwartz D. A., International Symposium on the Physics of Neutron Stars and Black Holes 93-96

Wood, K.S., Meekins J.F., Yentis D.J., Smarthers H.W., McNutt D.P., Bleach R.D., Byram E.T., Chubb T.A., Friedman H. & Meidav M. 1984, ApJS ,56, 507W

The Digitized Sky Surveys were produced at the Space Telescope Science Institute under U.S. Government grant NAG W-2166. The images of these surveys are based on photographic data obtained using the Oschin Schmidt Telescope on Palomar Mountain and the UK Schmidt Telescope. The plates were processed into the present compressed digital form with the permission of these institutions