Configuring the MONSOON Imaging System to Acquire Data from a CCD

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ABSTRACT

The object of my summer REU was to gain understanding of the way MONSOON functions and to configure it to work with a CCD. In order to observe the behavior of the CCD, it was exposed to different light conditions. The data coming off the CCD was analyzed using Mathematica programs I prepared for this purpose.

I. Background and Introduction

University of Illinois is part of a group of collaborating institutions working on the Dark Energy Survey (DES). The discovery that the universe is accelerating, not slowing down from the mass it contains, is the surprise that sets the initial research program of 21st Century cosmology. The Dark Energy Survey is a next generation sky survey aimed directly at understanding this mystery.[1] To do this a 40-cm diameter CCD camera is being built, and will be used in the existing 4-meter telescope at the Cerro Tololo Interameican Observatory.

The focal plane of the telescope will be upgraded to use 62 CCDs, each with a resolution of 2k by 4k pixels. This represents an overall resolution of over 500 M pixels. The amount of data this represents needs serious consideration when designing the system that will acquire the signals from the CCDs.

The survey will work over 5 years to obtain data from 5000 square degrees of the Southern hemisphere in the *g*,r, i and z wavelengths.

I(a). The Science Goals

Cosmic inflation and the accelerated expansion of the universe can be characterized by the equation of state of dark energy. In the simplest case, the equation of state of the cosmological constant is $w = -1$. More generally, the universe is accelerating for any equation of state $w < -1/3$.[2]

A goal of the survey is to be able to measure the state parameter w to a better accuracy than what is currently known. At the moment w is known to about 30%. The DES will use four different techniques to constrain w to 5-10%. These include:

(a) a galaxy cluster study in collaboration with the South Pole Telescope cluster survey,
(b) a weak lensing study of the fluctuation spectrum of dark matter,
(c) a galaxy angular power spectrum study and
(d) a SNe Ia study that will deliver ~2000 SNe Ia over the life of the project.[3]

I(b). The apparatus

One particular part that UIUC is working on in the DES is the image acquisition system, known as MONSOON. The system will drive the array of 62 CCDs that are located at the focal plane of the telescope. MONSOON will also read out the CCDs once an exposure has taken place.

A charge-coupled device (CCD) is a sensor for recording images, consisting of an integrated circuit containing an array of linked, or coupled, wells created by electric fields. Under the control of an external circuit, each well can transfer its electric charge to one or other of its neighbors. See Figure 1.

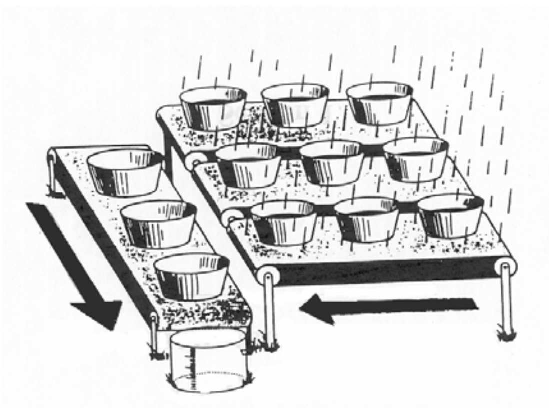

Figure 1: "Bucket Brigade" illustration of how the charges corresponding to different amounts of light are read off a CCD.[4]

When a photon strikes an atom, it can elevate an electron to a higher energy level, in some cases freeing the electron from the atom. When light strikes the CCD surface, it frees electrons to move around and they accumulate in the capacitors. Those electrons are shifted along the CCD by regular electronic pulses and "counted" by a circuit which dumps the electrons from each pixel in turn into a capacitor and amplifies and measures the voltage across it, then empties the capacitor.[5]

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II. Method

In the first part of the summer project, we configured the MONSOON system to send out the signals needed to drive and read out a Sony ILX503A CCD [see Fig. 2]. The ILX503A is a CCD linear sensor designed for facsimile, image scanner or OCR use.[6] It is a one-dimensioned array of 14 μm large pixels, with a length of 2048 pixels. The CCDs that will be used with MONSOON, however, are two dimensions: 2k by 4k pixels. We used the ILX503A because it is robust enough for use in normal laboratory conditions in room temperature.

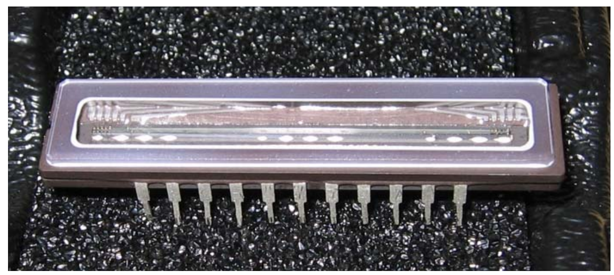

Figure 2: The Sony CCD is 4cm in length and connects to a circuit using 22 pins

MONSOON uses three buses to drive and read out the CCD. One is for the clock signals; the second for bias voltages; and the third is for the output of the CCDs. The ILX503A requires two supply voltages and for the configuration used, two clock signals. Instead of powering the CCD using the bias voltages, the CCD was connected to two external power sources. The data acquisition card is still being built, so the output of the CCD output was read using a Tektronix TDS 224 digital oscilloscope. The scope was connected to a desktop computer so that data could be stored and analyzed.

The documentation for the CCD included a circuit needed to obtain proper CCD readout. I put together a circuit following this design using temporary wire-wrapping, which would allow for easy modification of the circuit throughout the summer.

Once the circuit was built, we programmed the computer to generate the required clock signals. Code was written in sequencer files. Code from previous CCD configurations was adapted per the specifications of the Sony CCD. The first clock signal to the CCD signifies the start of the readout, and the other clock signal drives the CCD to read out the electrical signals stored in the pixels.

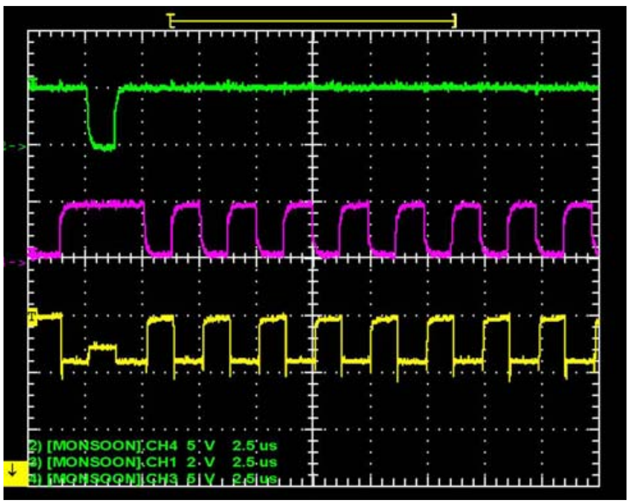

Figure 3 Clock Signal to Drive the Sony CCD. Top Signal: tell the CCD when to start reading out conents of pixels. Middle Signal: Square wave generated where the peak of the wave corresponds to the output of the pixel seen as a "well" on the Bottom signal

The sequencer file works by creating states representing the different possible combinations of the two clocks. Each clock can be on or off, in other words a predetermined high or low voltage. In the case of the Sony CCD, this is 5 V and 0 V respectively for both clocks. In all there would be 4 different states, the 4 possible permutations of two possibilities on two channels. The sequencer has a specific set of instructions used in programming what states are activated and when. Once a state was made active, it can be kept that way for a time by calling a "delay" of specified length. The smallest unit of a delay was 1 μs. This would be the duration a half of the CCD readout cycle, so each pixel would be read out every 2 μs, or at a rate of 0.5 MHz. This is well within the maximum clock frequency of 5 MHz required by the Sony CCD.

The first signals obtained from the CCD had small oscillations. The voltage reading for each pixel was not steady enough over the time it was being read out. (See Figure 4) It was therefore necessary to further modify the circuit with capacitors. We decided that the external power supplies were most likely introducing the oscillations. We connected one end of capacitors to every pin on the CCD that had an input voltage, with the other end of the capacitors being grounded. This solved the issue satisfactorily (See Figure 5).

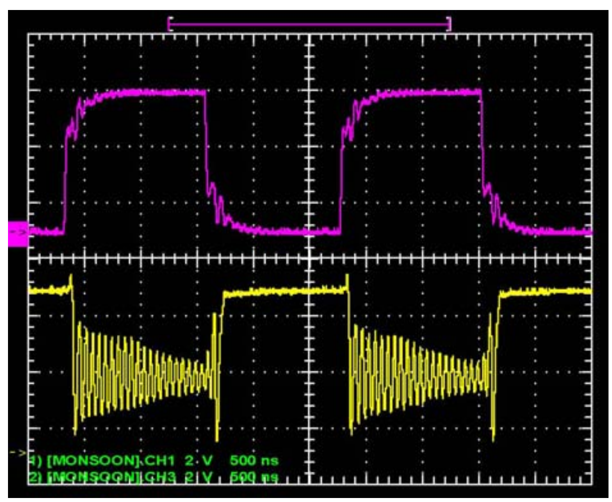

Figure 4: Top: Clock signal and Bottom: output signal without capacitors in circuit

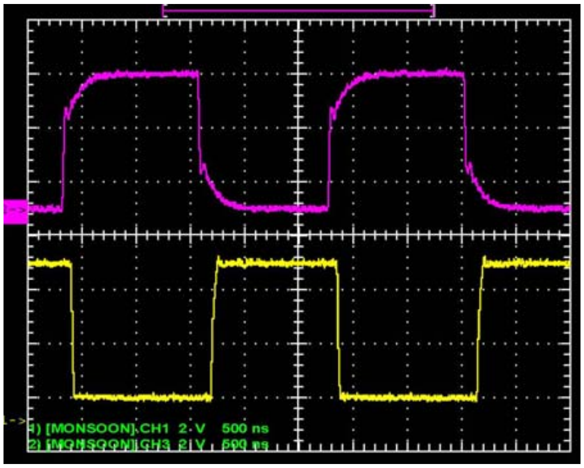

Figure 5: Top: Clock signal and Bottom: output signal with capacitors in circuit. The top of the output signal is a baseline voltage, while the bottom of each well represents the voltage being read off of the pixel.

Once the CCD was outputting the right signals, it was necessary to set up a light source. The power of the ambient light in the laboratory was excessive as it saturated the CCD, and couldn't be kept constant. A small lightproof enclosure was built around the CCD. A red LED was placed at the top of the enclosure pointing down onto the CCD.

The LED was powered using the clock signals from the control board. The sequencer file was easily modified to include the LED in the possible states. The length the LED remained lit could be controlled by specifying how many times a delay loop would be carried out.

The Tektronix oscilloscope has a resolution of 2500 data points at any given time. The CCD itself is 2048 pixels, and to discern the individual pixels, at least two data points are needed: one for the bottom of the voltage "well", and one for the other half of the signal that occurs between the two pixels (See figure 5.). The data points are taken by the oscilloscope every certain time period, and it is impractical to try to align the data points with the bottoms and tops of the signals. A larger amount of data points, in this case between 12 and 14 were allotted to each pixel signal. For us to achieve this it was necessary to break up the 2084 into 11 smaller segments. Data points were read out for each segment 10 times.

At 2500 data points for 11 segments, 10 readouts each ends up being several hundreds of thousands of data points for each configuration. A configuration might include a specific time the LED was lit, or a pattern placed on the CCD.

I spent the latter part of the summer programming code in Mathematica to take the raw data and process it into a more useful form. The average of the data points within each well was taken, and then stored in a new file. The values could then be graphically displayed and further analyzed.

III. Results and Discussion

Once the setup was understood and the processing code was functioning, a variety of configurations were tested so the behavior of the CCD under different exposures could be understood.

One characteristic of a CCD that needs to be studied is how it responds to quantities of light. The charge within a pixel is proportional to the amount of light exposed to it, up until a certain point when the wells become saturated. To observe this, a range of exposure times was used. The geometry of the setup was not changed throughout the different readings, in hope that individual pixels could be compared from exposure to exposure. These readings spanned several days, so it was necessary to check for changes in the setup from day to day. The set up was not physically altered, and the same intensity of light was tested on different days, and the differences in the results were on a very small scale (on the order of 1%, no larger than the measured precision). From this it can be assumed that the conditions in the room and of the setup were continuous enough that comparing configurations done on different days is valid.

The first configuration was no light whatsoever. After that, light was exposed in different quantities in steps of 2.5 ms up to 25 ms. (The actual times are slightly larger as the time for each delay cycle on the control board is slightly larger than 1 μs. However, the amount of light hitting the CCD is only related to this time, thus the units are arbitrary.)

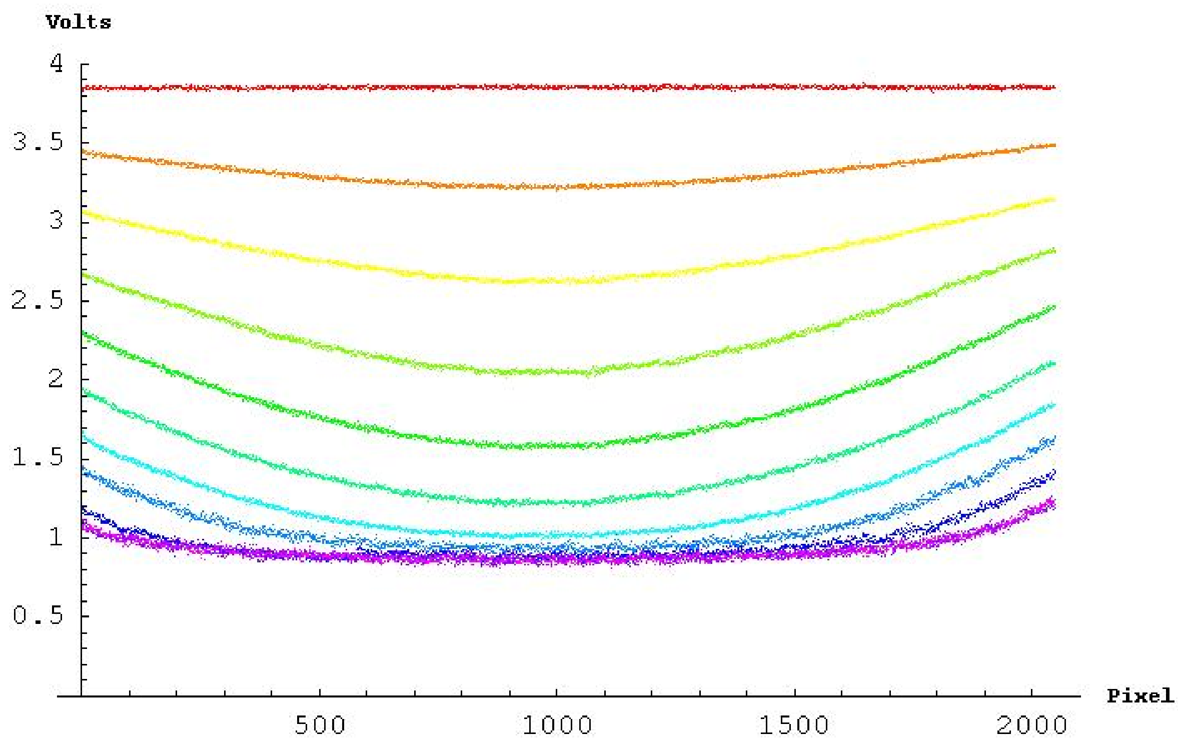

Figure 6: The red plots are for light at 0ms, and each line below that is an additional 2.5 ms of exposure to light

As seen from Fig. 6, the intensity of the light is not uniform over the CCD. We wanted to find out if the reaction to light was different from pixel to pixel.

Figure 7. Shows the behavior of just two pixels under different amounts of light.

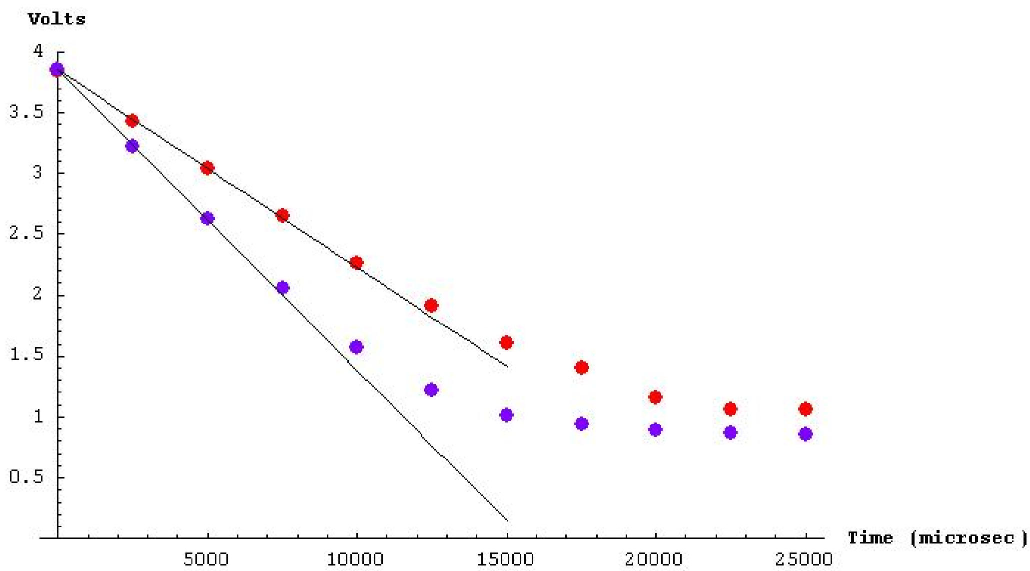

Figure 7: Red Plot: Pixel Closer to Edge, Purple: Closer to middle. The Time axis represents time that the CCD was exposed to light

For low intensities of light the reaction of the two pixels is linear, and after about 7.5 ms the pixel starts to reach saturation level, at which it can no longer hold charge.

Since the exact amount of light hitting a pixel is unknown as the geometry of the LED is unknown, you have to scale the data from one pixel to compare it to another.

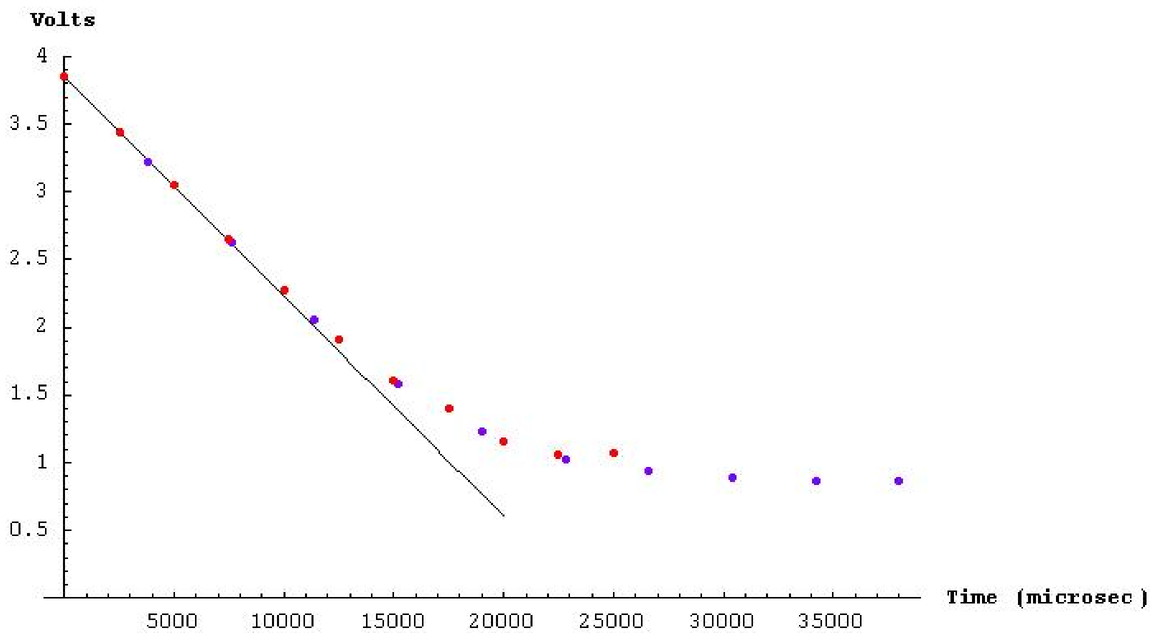

Figure 8: Purple plot has been scaled to red plot The Time axis represents time that the CCD was exposed to light

Figure 8 shows the purple plot has been scaled so that the first few data points (the linear ones) fall on the same line. Each point is scaled along the x-axis with equal proportion.

This can be done with the entire set of exposures over all the pixels. Figure 9 shows this plot

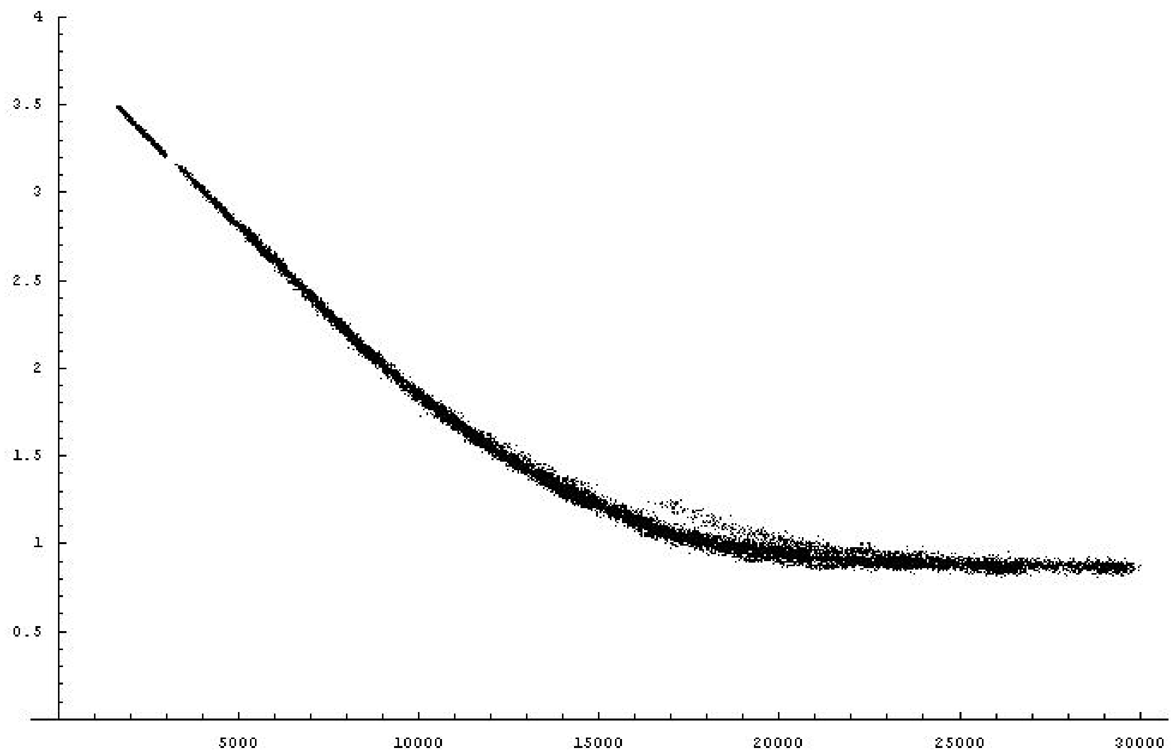

Figure 9: Scaled plots

IV. Conclusions

The close proximity of the points in Figure 9 suggests that regardless of what pixel in the CCD you are observing, it is behaving just the same as any other one. A less distinct curve seen in Figure 9 would have meant the CCD we used was not very uniform when it reacted to proportional quantities of light.

The small band of points around the region of 19,000 on the x-axis represents data from the ends of the CCD. As seen in Figure 6, the ends of the CCD did not reach the same saturation voltage as the rest of the CCD. One possibility of this behavior is a characteristic of CCDs: blooming. When the light signal is beyond the saturation level (as was the case of the middle of the CCD), charge from pixels spills into adjacent pixels. It could be that the spilling only occurred in an area in the middle, but the largest amount of light was still not enough to fill all the CCD's pixels, just those in the middle.

It is extremely essential to know a characteristic curve as the one in Fig. 9. Such values as the saturation voltage, and what voltage no longer represents a linear change in the intensity of light can be obtained from such analysis.

A more thorough investigation of this CCD would call for the use of a calibrated light source with a known behavior. The properties of the LED that was used were not known, and it is possible that the fluctuations in the output contributed to less precision in the experiment.

This plot however, represents a large amount of time spent taking data off the oscilloscope. A dedicated data acquisition card for MONSOON is being built and will sample and record the output of the

CCD in one exposure, as opposed to having to break up the signal into smaller parts. This will allow large amounts of CCDs to be tested before finally being used in the telescope.

V. Acknowledgments

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IV. References

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