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Chapter 1 INTRODUCTION

When the light from a star passes through the earth's atmosphere, it is refracted many times by the turbulent atmosphere. This introduces image motion and distortion at the telescope. In addition, the telescope itself introduces image motion due to wind-shake and imperfect mechanical couplings to its drive motors, the dome, and other sources of vibrations. Exposures of a star that are several seconds or longer will show a blurred star due to the image motion introduced by the atmosphere and telescope. The WIYN Tip-Tilt Module (WTTM) is used to compensate for the motion of the image caused by the atmosphere and telescope vibrations. Much higher resolution images than would normally be possible are the result.

The WIYN Tip-Tilt Module is an optical and near-IR reimaging system that utilizes fast tip-tilt compensation and includes real-time focus sensing. The field of view for the WTTM is $3.84 \times 4.69$ arcminutes at a plate scale of 0.1125 arcseconds per 13.5µm pixel. The WTTM is attached to the WIYN Instrument Adapter System (IAS) at the Nasmyth focus. Changing between the WTTM and the MiniMosaic imager is accomplished by moving a pick-off mirror (~30 seconds).

This document is divided into 6 main chapters and 4 appendices. The first is this introduction. The second is a description of the physical layout of the instrument and some of the optical principles involved. Chapter 3 Observing Run Preparation, details what astronomical programs will benefit most from using WTTM and the preparation necessary prior to an observing run. The fourth deals with the mechanics of setting up and actually using the instrument. The Data Reduction section deals with basic calibration issues, as well as the differences between reducing WTTM data and other imaging data. Finally, Chapter 6 Data Handling, gives some suggestions on how to backup and store data acquired using the WTTM system. The 4 appendices give performance characteristics, a list of command line interface (cli) commands, suggested dome flat settings and checklists for quick setup for the instrument in the afternoon and science fields during the night.

Minimally, please read chapters 2-5 at least once prior to using WTTM. This is not simply another imager and using WTTM is both a highly active and non-intuitive process. Reading the documentation will improve understanding of the instrument and decision making when choosing WTTM settings during the night.
Chapter 2 WTTM Instrument Description

This section describes the WTTM design and implementation with the aim to make the observer more familiar with its theory and operation. The section 2.1 covers the optical path, section 2.2 the tip-tilt error sensor and section 2.3 the science camera itself.

2.1 Hardware

2.1.1 Principles

The WTTM optical design is essentially a modified Offner reimaging system. The modification comes about by the 1:1.15 magnification in the WTTM, where an Offner reimager is strictly 1:1. This design was chosen to meet the requirements of plate scale and image sampling within the constrained space envelope surrounding the WIYN IAS.

2.1.2 The Optical Path

Understanding the optical path is essential for proper interpretation of the data obtained from the WTTM along with analyzing problems as they occur during an observing session. Incoming light passes through the dome slit onto the 3.5m WIYN primary and on to the secondary, then to the tertiary mirror. The tertiary mirror is used to select between the three major instrument ports on the WIYN telescope. The two Naysmith, MOS and WIYN imaging, ports are selected by rotating the tertiary mirror through 180 degrees, and the Cassegrain port is selected by flipping the tertiary out of the main telescope optical beam to allow the light from the secondary to pass through to the f/13.7 cassegrain-reimaging optics.

The WTTM is located on the WIYN imaging Naysmith port as an addition to the IAS. This port also supports the WIYN Mini-Mosaic 4kx4k CCD imager. With the WIYN port selected light reflecting off the tertiary passes through the elevation bearing and into the IAS. When the WTTM is in use the light inside the IAS is redirected to one side by inserting a 45-degree flat mirror. This mirror (WTTM-slide) is located in front of the focus and guide probes. This mirror also shares the same mechanism as the pick-off mirror for the wavefront camera (WFS-slide). Approximately 10 inches after the WTTM pick off mirror the light comes to its nominal focus. This is equivalent to the focus position used for the Mini-Mosaic.

Coincident with the folded focus is a square aperture mask or field stop. This is where the WTTM proper begins. Inside the WTTM the light follows a zig-zag path off M1, tip-tilt mirror, M2, and M3 before arriving at the beamsplitter. At the beamsplitter the light is divided between the science camera and error sensor. The beamsplitter is oriented at a 45-degree angle to the incident light, where the front surface reflection directs the light to the science camera parallel to the beam on the Mini-Mosaic and the path through the beamsplitter goes to the error sensor. In the science beam after the beamsplitter the light leaves the WTTM proper and enters the filter wheel, where one of eight 2”x2” filters are selected. The filters are intended to be 5mm±1mm thick, in order to maintain the focus conjugate between the science camera and error sensor. The remaining optical element in
the science path is the quartz dewar window. In the next section we will discuss in detail the optical path in the error sensor and its functions.

2.2 ERROR SENSOR

2.2.1 DESIGN AND OPTICAL LAYOUT

In designing the error sensor our principal aim was to maximize its overall throughput, so that for any given guide star the highest correction rates could be achieved. The generic design concept follows the successful implementation of the tip-tilt correcting system HR-CAM at the CFHT. This design used a quadrant image dissector with each quadrant feeding a photon counting detector coupled by fiber optics cable.

2.2.2 TIP- TILT CORRECTIONS

Analysis of the 4 photon counting detectors allows the calculation of apparent stellar motion in two axes, nominally \( x \) and \( y \). These errors are then used to adjust the attitude of the tip-tilt mirror to correct for image motion. The corrections are based on the following equations:

Equation 1 - Summation of Quadrants

\[
\sum_{i=1}^{4} Q_i = \text{Sum of counts in the 4 quadrants}
\]

Equation 2 - X Tip-Tilt Error

\[
X_{\text{error}} = \frac{(Q_2 + Q_3) - (Q_1 + Q_4)}{\sum_{i=1}^{4} Q_i}
\]

Equation 3 - Y Tip-Tilt Error

\[
Y_{\text{error}} = \frac{(Q_1 + Q_2) - (Q_3 + Q_4)}{\sum_{i=1}^{4} Q_i}
\]

where \( Q_i \) represents the number of counts in quadrant \( i \) in a given time interval. These errors are multiplied by the gain setting in order to correct part of the calculated error. In general these calculations and tip-tilt updates are done at least 100 times per second. By correcting only a portion of the error at a relatively high frequency it is possible to minimize the effects of noise in the quadrant counts on the system. Lab tests indicate that a frequency of 1000 Hz is easily obtainable and this is considered the usable maximum for the system on sky. In practice the maximum frequency will often be set by the magnitude of the tip-tilt star. In order to get enough counts in each quadrant for the tip-tilt error calculations to be meaningful the system may have to be operated at a slower frequency.
2.2.3 **Telescope Control System Guiding**

Telescope tracking corrections are required to provide the full dynamic range of tip/tilt correction. Without such tracking corrections the tip/tilt of the mirror will remove tracking errors by compensating with tip and/or tilt. This can lead to the tip/tilt mirror moving to a limit in one or both of the tip/tilt axes.

Telescope tracking corrections can be provided either via the IAS guide probe or by WTTM itself (preferred) by eliminating any time-averaged bias in the tip/tilt position. These corrections are on a much longer time scale than the tip-tilt corrections (~1 – 5 seconds). The time scale is set by the observer based on observing conditions.

2.2.4 **Sensing Focus**

When a converging optical beam, such as that from a telescope, passes through a piece of glass aberrations are produced. When the beam is normal to the glass spherical aberration is the dominant term produced. As the beam is tilted relative to the glass both astigmatism and coma are produced, with the total amount proportional to the beam f-number and thickness of the glass. In the WTTM the path to the error sensor passes through some 12 mm of glass at an incidence of approximately 45 degrees. The compensator element corrects for all the spherical and chromatic aberration and ~80 % of the astigmatism. The remaining astigmatism is used to sense focus.

Astigmatism is characterized by having two different foci in a 2-theta geometry, where theta refers to the position angle in the plane of the telescope pupil. These are called the sagital and tangential foci and result in elliptical images with their major axes rotated by 90 degrees respectively. The WTTM error sensor is aligned such that the major axes fall along the diagonals of the quad-cell geometry. Thus, the ratio of flux along the two diagonals in the quad-cell is sensitive to changes in focus.

**Equation 4 - Z (Focus) Tip-Tilt Error**

\[
Z_{error} = \frac{(Q_1 + Q_3) - (Q_2 + Q_4)}{\sum_{i=1}^{12} Q_i}
\]

Gives the value which is used to control the focus. Because there are two optical elements in the science beam which are not in the error sensor beam (the filter and the dewar window) and because there are three optical elements in the error sensor beam which are not in the science beam (the beamsplitter, the aperture wheel and the compensator element) this value is rarely zero when the science image is in focus. It is designed to be as close as possible, but the filter thicknesses have some error and are not 100% uniform. Therefore the value of \( Z_{error} \) is measured each time the telescope is focused to determine a set point and then the WTTM sends commands to the TCS based on deviations from the measured set point.
2.2.5 Avalanche Photo Diode Safety Issues

!!Warning!!: The WTTM error sensor detectors can self destruct from over exposure to bright light!

Like the CFHT’s HR-Cam the WTTM uses Avalanche Photo Diode (APD) modules as the photon counting detectors. These detectors produce a pulse for each photon detected that is then counted by an electronic counter inside the WTTM computer. These are the values represented by $Q_1$ thru $Q_4$. APDs have a property of emitting a cascade of photons during the avalanche process. Because of this a small amount of heat is dissipated in the very small (~500 µm diameter) APD with each photon detected. Under normal operation a thermoelectric cooler inside the module removes this heat. However, a severe consequence of this property is that it is possible with very high photon rates for the APD to destroy itself. Therefore, it is essential to avoid exposing the APDs to very bright light, e.g. direct sunlight, moon, stars brighter than 7th magnitude, flat lamps, etc. If you can see it with the unaided eye it is too bright for the APDs.

The WTTM’s APD modules are select units that have been specifically modified to enhance the performance over that quoted from the factory. These modifications include specially selected hermetic windows for optical quality, anti-reflection coatings on both sides of the hermetically sealed window and similar coatings on the fiber coupling. While small individually, the modifications result in ~20% increase in net sensitivity of our APD modules over the factory delivered modules. Thus, the APD modules in the WTTM are essentially irreplaceable, as this effort is unlikely to be repeated.

2.2.6 Performance Metrics & Parameters

There are several values which are used to determine the performance of the WTTM. The values of $X_{error}$, $Y_{error}$ and $Z_{error}$ will have some noise associated with them. However, the amount of scatter in these terms, their variance, should be as small as possible.

Adjustment of the various parameters controlling the WTTM, the brightness of the tip-tilt star, the native seeing on a given night, the filter and beamsplitter selected and the distance from the tip-tilt star will all have effects on the final delivered image quality of a given science target.

The WTTM user has control over several of these factors:

1. Choice of star – This may be the most important factor because it influences the possible choices for several other parameters. The star should be chosen to be bright enough to use a relatively large tip-tilt update rate. The star should also be as close to the science object as is possible.

2. Acquisition Frequency – This is how often the counters which are “fed” by the APDs are read out. Sampling theory suggests that in order for the tip-tilt system to correct for a vibration or other cause of an image deviation from a central position it is necessary to sample the error signal at ~ 10 times the frequency of the deviation which is to be corrected. There is a minimum number of counts necessary to provide a usable signal to noise in the calculations of $X_{error}$ and
\( Y_{error} \). The number of counts in any quadrant is inversely proportional to the acquisition frequency.

3. Data Input/Output (DIO) Frequency – This value represents how often updates are sent to the tip-tilt mirror. It is possible to set this value to a number smaller than the Acquisition frequency and the software will average several of the results calculated for \( X_{error} \) and \( Y_{error} \) before sending corrections to the tip-tilt mirror. This provides a low-pass filter effect to the tip-tilt corrections and should probably only be used if one suspects that there is excessive noise in the \( X_{error} \) and \( Y_{error} \) calculations.

4. X and Y milligains – These values represent the amount of \( X_{error} \) and \( Y_{error} \) corrected for any single calculation of the values. For example, if the system were perfect, the DIO and Acquisition frequencies set to 1000 Hz and the milligains set to 100, then if an image deviated from its nominal position by 1 arcsecond the tip-tilt system would move the image back 0.1 arcseconds toward its nominal position in 0.001 seconds.

5. Z milligain – This value is similar to the X and Y milligains but controls the amount of correction that is applied to the telescope focus after each focus interval. The optimal value of the Z milligain is dependent on the seeing. For “very good” seeing the value of the Z milligain should be “small”; for “poor” seeing the value should be “large”. Typical values range from 100 to 1000.

Other factors are either set by the observing program or are simply a result of the weather on a given night. These factors still effect how the WTTM works and the selection of the WTTM parameters.

1. Tip-Tilt Star Magnitude – This relates directly to how fast one can set the Acquisition frequency and still achieve reasonable count rates in the four quadrants of the error sensor. The brighter the star the higher one can set the Acquisition frequency. It is important to remember that the beamsplitter is only going to let 5-15\% of the light incident on it reach the compensator element and that the star will have reflected 8 times before getting to the beamsplitter. The flux at the science detector is going to be 5-20 times higher than that at the error sensor.

\[
\log_{10}\left(\frac{R_m - BS_{const}}{-2.5}\right) = \text{counts }/ \text{s}
\]

\[
R_m = BS_{const} - 2.5 * \log_{10}(\text{counts }/ \text{s})
\]

where \( R_m \) is the R magnitude of a star and \( BS_{const} \) is the beamsplitter constant. For the 85/15 beamsplitter \( BS_{const} = 22.82 \) and for the 95/5 \( BS_{const} = 21.52 \). Both these formulae and the graph below may be slightly misleading for very blue stars since there is no filter in the error sensor light path.

The recommended faint limit is 15.5 for the 85/15 and 14.0 for the 95/5. This assumes photometric conditions. This will give 10 counts above background @100Hz.
To get 25 counts above background @300Hz the limiting magnitudes for the 85/15 and 95/5 are 13 and 12 respectively.

2. Tip-Tilt Star Position – The closer the star is to the science object the better. It may even be the science object. The reason for this is that the amount of correction provided by the WTTM falls off with increasing distance from the guide star. The coherence of image motion over the field of view of WTTM is extremely good so this should be ranked as a minor priority when picking tip-tilt stars.

The other factor when choosing the “position” of the tip-tilt star is that it should be well-isolated. There should be a minimum of 10 arcsec from other objects of similar or greater brightness. The tip-tilt star should also be a true point source.
3. Seeing – Yes, there is nothing anyone (including your operator) can do about the native seeing on a given night, however, by taking account of the seeing one may be able to pick parameters for WTTM which make the most of the conditions available. This is particularly true of the focus settings.

The relationship between $Z_{\text{error}}$ and telescope focus is not always linear. There is a linear portion of the relationship around the point where $Z_{\text{error}}$ is zero. The slope of this linear portion and its focus coverage before going non-linear are dependent on the seeing. The better the seeing the steeper the linear relation and the smaller the range on either side of zero that the relationship is linear. This means that as the seeing improves the focus milligain should be set to smaller numbers and the telescope must be in focus before focus corrections are enabled.

4. Filter and beamsplitter – Although these are generally dictated by the science program it is important to remember that the beamsplitter sends a different amount of light to the error sensor than it sends to the science camera and that stars which may not be visible in some narrow band filters may be useable as tip-tilt stars. If this is the case then a test exposure in a broadband filter to select a tip-tilt star may be necessary.
2.3 Science Camera

2.3.1 System Description

2.3.2 System Performance and Specifications

2048x4096 pixel detector

13.5µm pixels @ 0.1125”/pixel

43mm circular filter aperture

2048x2500 readout @ 16 bits/pixel with header and overscan ~10.58 Mb

FOV = 3.84 x 4.6875 arcminutes vignetted at corners

Gain setting 3 = 5µs dwell time

readout = 2.6 minutes @ 5µs dwell time

read noise = 3e− @ 5µs dwell time

gain = 1.3e−/ADU @ 5µs dwell time

linear to 75,000 e− at 0.1%

Number of Counts Vs. Stellar Magnitude

\[ y = 9E+09e^{-0.9039x} \]
Table 2-1 Count Rates in Counts per Second

<table>
<thead>
<tr>
<th>Filter</th>
<th>U</th>
<th>B</th>
<th>V</th>
<th>R</th>
<th>I</th>
</tr>
</thead>
<tbody>
<tr>
<td>Beamsplitter</td>
<td>85/15</td>
<td>95/5</td>
<td>85/15</td>
<td>95/5</td>
<td>85/15</td>
</tr>
<tr>
<td>Magnitude</td>
<td>7</td>
<td>8</td>
<td>9</td>
<td>10</td>
<td>11</td>
</tr>
<tr>
<td></td>
<td>15</td>
<td>16</td>
<td>17</td>
<td>18</td>
<td>19</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>432600</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>11600</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>315</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

2.3.3 FOV: Why it looks the way it does

The WTTM CCD shutter and/or the field stop? vignettes the field and forces the “circular” field of view with a flat cutoff on the ‘top’.

2.3.4 Beam-splitters for Science

Currently there are two science grade beam splitters available. The first reflects 85% of the light incident on it to the science detector and passes 15% through to the error sensor. The 2nd reflects 95% of the light and passes 5%. There is a third beamsplitter that was used during commissioning which is a 50/50, however it is not considered a science-grade beamsplitter.
2.3.5 **Aperture Wheel**

There is an aperture wheel in front of the APDs to limit the amount of scattered light incident on them. It is highly recommended that the observer only use aperture #5 and possibly #4. The reason being that any vignetting of the tip-tilt star going to the APD will invalidate the tip-tilt results.

<table>
<thead>
<tr>
<th>Aperture Number</th>
<th>Aperture Diameter</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0.5”</td>
</tr>
<tr>
<td>2</td>
<td>0.707”</td>
</tr>
<tr>
<td>3</td>
<td>1.00”</td>
</tr>
<tr>
<td>4</td>
<td>1.414”</td>
</tr>
<tr>
<td>5</td>
<td>2.00”</td>
</tr>
<tr>
<td>6</td>
<td>2.83”</td>
</tr>
</tbody>
</table>
Chapter 3 Observing Run Preparation

3.1 Scientific Justification

3.2 Proposal Submission

3.3 Pre-run Checklist
Chapter 4 NIGHTLY USE

The WTTM requires two computer systems, as well as certain hardware components to be configured and functioning for proper operation. This section takes you through the essential elements of this configuration. You should allow approximately 1 hour for this. This section only covers WTTM specific configuration issues and does not cover data related issues such as calibration frames, photometry and data archiving. See Chapter 5 for suggested information required for proper reduction and calibration of your data.

4.1 Setting up the WTTM Software

The WTTM software system operates under the Linux operating system, currently RedHat v6.2 on a dual 500MHz Pentium III CPU machine. The computer chassis is located under the telescope azimuth skirt and is named wiyn-wttm. Located below the wiyn-wttm chassis is the error sensor X-Y stage control chassis.

Full operation of the WTTM requires the observer to use two computers called Sand and Navajo. Sand is the computer used for Minimosaic observing and serves only as a display console for the WTTM computer, wiyn-wttm. Navajo serves as the data acquisition computer that runs the ARCON CCD control system.

4.1.1 Sand/wiyn-wttm

At present six GUIs are brought up to control the WTTM. The following subsections detail how each GUI is set up.

4.1.1.1 Logging in

The first task is to start up the Tip-tilt software on wiyn-wttm and have the GUI’s displayed on Sand. Start by logging onto Sand as “wiyn_ccd”. The password should be the normal mountain user password and should be posted on the monitor.

4.1.1.2 Exporting the wiyn-wttm display to Sand

Once logged in, open a new terminal by clicking the right mouse button anywhere on the screen and choosing the “Unix Xgterm” menu item. In this terminal window, type:

wiyn_ccd@sand% ssh wttm@wiyn-wttm

the password is once again the normal mountain password. At this point any commands that would normally bring up X-windows clients will display on Sand.

4.1.1.3 Labview GUIs

In the terminal window, which should now have a [wttm@wiyn-wttm wttm]$ prompt, type:

[wttm@wiyn-wttm wttm]$ wlv start

This will start the WTTM Labview software that enables the user to control the operation of the tip-tilt module. A few status messages will appear followed by the list of commands detailed in Appendix 2: CLI Commands. Five GUIs with titles: wttmPublish,
wttmControlVI, wttmGetTaskValuesVI, wttmGuiderVI, and wttmFocusVI will then appear on Sand’s monitor. Using the WttmControlVI window the user sets the parameters controlling WTTM performance. The other GUIs give feedback showing the user how well the WTTM is performing. The user may want to minimize the wttmPublish as it is only needed when troubleshooting the system. Next click on the EXIT button on the wttmGuiderVI and wttmFocusVI GUIs and then choose the Quit options from the File pull-down menu. On Sand’s second monitor open another Unix Xterm. In this terminal window, type:

```
wiyn_ccd@sand% ssh wttm@wiyn-wttm
```

the password is once again the normal mountain password. Then type in:

```
[wttm@wiyn-wttm wttm]$ wttmGuiderVI &
[wttm@wiyn-wttm wttm]$ wttmFocusVI &
```

N.B. The current GUIs are being streamlined and refined please submit any comments and suggestions you have on the GUI’s to corson@noao.edu.

<table>
<thead>
<tr>
<th>Labview Module</th>
<th>Purpose/Function</th>
</tr>
</thead>
<tbody>
<tr>
<td>WttmPublish</td>
<td>History of commands sent</td>
</tr>
<tr>
<td>WttmControlVI</td>
<td>Controls WTTM acquisition parameters</td>
</tr>
<tr>
<td>WttmGetTaskValuesVI</td>
<td>Provides visual plots</td>
</tr>
<tr>
<td>WttmGuiderVI</td>
<td>Tracks guider XY signal and corrections</td>
</tr>
<tr>
<td>WttmFocusVI</td>
<td>Tracks focus (Z) signal and corrections</td>
</tr>
</tbody>
</table>

4.1.1.4 APD XY Alignment GUI

To start the GUI to position the error sensor type:

```
[wttm@wiyn-wttm wttm]$ /home/wttm/development/bin/xyManVI.alpha &
```

When this command is issued the user will be asked a series of questions. In general the user should operate this GUI in calibrated mode using the most recent version of the .forward and .reverse files.

Figure 2 APD XY Alignment GUI shows the window that comes up. However, the user may resize it to hide the graphic on the right side of the GUI without any loss in efficiency. The APD XY Alignment GUI should be easily accessible.
4.1.1.5 Command Line Interface

The WTTM has an extensive command line interface, as documented in Appendix 2: CLI Commands (the information in this appendix is also available by typing `wh` at the CLI prompt).

NOTE: Most commands accept a ‘-h’ parameter to provide a single line of help text.

The terminal that is used to start all of the GUIs will serve as the command line interface (cli). All cli commands are shell commands and begin with the ‘w’ identifier.

For a greater detail on the cli commands and all of the other GUIs (from a programmers point of view) refer to “WTTM Software Manual” (a.k.a. WTTM Users’ Manual) by P.N. Daly (there should be a copy in the WIYN control room).

4.1.2 Navajo

The data acquisition takes place on Navajo. Login as “wiyn_ccd”. The password should be posted on the monitor. Along with various ARCON windows, an IRAF Data Acquisition Window and an IRAF Data Reduction Window open up. An Ximtool window also opens up which shows the most recently acquired image. Right click and (Re)start ARCON if it is not already running. In order to bring the ARCON software up the user will be asked if they want to syncronize parameters (the answer to this is yes) and what filter is in wheel 1 (the answer to this is the short name of the filter in position 1). All acquisition and analysis commands are given on Navajo.

N.B. Behind the Ximtool there should be a DCA GUI. When first starting up the system there may simply be a window behind the Ximtool asking if the user wants to start the DCA. This must be answered “yes” before data may be acquired.
4.1.2.1 ARCON Acquisition System

The ARCON acquisition system works exactly like the MIMO system writing data as multiextention fits files. The observe command will allow the user to take any type of image. The test command will allow the user to take any type of exposure and will write it to test.fits. A new test command will overwrite the test.fits file. In order to examine images it is recommended that the user bring up a separate Data Reduction window if one is not already running. The ARCON will experience fewer problems if it is only used for data acquisition.

4.2 Configuring the WTTM Hardware

All of the hardware should have power available and be physically configured by the Telescope Support personnel and should not need to be turned off throughout the users run. Currently, switching beam-splitters should only be done during the daytime by Telescope Support.

4.2.1 Avalanche PhotoDiodes

!!Warning!!: The WTTM error sensor detectors can self destruct from over exposure to bright light!

In the wttmControlVI set the APD/DIO frequencies and the APD/DIO update rates as shown in Figure 3 WTTM Control GUI. But keep the X,Y and Z milligains set to zero, to keep the loop open. Set the APD0-3 Milligains to the values listed in Table 4-3 Default Control Values – APD Normalization Constants for the appropriate aperture. Hit the Set Parameters button and then Start Acquisition. The user will notice that the APD counter in wttmGetTaskValuesVI comes alive. However, the number of counts in all 4 APDs is zero because, during the startup, the power in the APDs is off by default (to increase the longevity of the APDs). To turn the power in the APDs on, issue the command:

[wttm@wiyn-wttm wttm]$ wttm_pwr apd on

Similarly [wttm@wiyn-wttm wttm]$ wttm_pwr apd off turns the power to the APDs off. When the power to the APDs is turned on, a brief surge of counts from each APD is seen. After this brief surge, the counts will come down to ~2 or 3 counts for each APD.

N.B. Please turn off the APD power anytime they are not in use. This is especially important when setting up for flatfield calibrations.

To verify the APD milligains (aka APD Normalization constants):

1. Setup on flat field with High Lamps at 750
2. set x/y position to 1100/1100 x/y pixel or ~20,000/20,000 encoder units
3. begin acquisition
4. run the script NormalizeAPDs in a cli window
5. obtain 100+ points (cntl-c to stop)
6. obtain mean of 4 channels after 100 points
7. normalization constant for channel \( x \) is:

\[
\text{Mean} \times 1000 / \text{counts in ch} \times = \text{ch} \times \text{normalization constant}
\]

### 4.2.2 Filters

The filters are 2x2 inch filters 5mm thick. The thickness is extremely important due to the need to conjugate the error sensor with the science detector. Filters are only in the science beam and must have a uniform, known optical thickness. Because the filters are not all exactly the same optical thickness there are small focus offsets between them, as shown in Table 4-2 Available Filter.

<table>
<thead>
<tr>
<th>Filter Number</th>
<th>Filter Name</th>
<th>Focus Offset (µm)</th>
<th>Filter Thickness (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Kron B</td>
<td>+20±5</td>
<td>5.105</td>
</tr>
<tr>
<td>2</td>
<td>Kron V</td>
<td>Unknown</td>
<td>5.055</td>
</tr>
<tr>
<td>3</td>
<td>Johnson R</td>
<td>Reference</td>
<td>5.029</td>
</tr>
<tr>
<td>4</td>
<td>Kron I</td>
<td>0±2</td>
<td>4.902</td>
</tr>
<tr>
<td>5</td>
<td>Sloan g´</td>
<td>Unknown</td>
<td>4.902</td>
</tr>
<tr>
<td>6</td>
<td>Sloan r´</td>
<td>Unknown</td>
<td>4.953</td>
</tr>
<tr>
<td>7</td>
<td>Sloan i´</td>
<td>Unknown</td>
<td>5.055</td>
</tr>
<tr>
<td>8</td>
<td>Sloan z´</td>
<td>Unknown</td>
<td>5.131</td>
</tr>
</tbody>
</table>
4.2.3 Beam Splitters
See section 2.3.4 Beam-splitters for Science.

Currently there are three available beam splitters. The first is an engineering grade 50/50 beamsplitter. The other two are science grade beamsplitters with 85/15 and 95/5 reflectance/transmittance respectively.

The 50/50 shows a small ghost image from a reflection off the back surface of the beamsplitter.

The science grade beam-splitters are currently being characterized.

4.2.4 Error Sensor
The alignment of the error sensor to the science detector is based on a mapping determined by the WIYN staff. Check with the staff that the error sensor mapping is still valid. If a new map is necessary it will be undertaken during the daytime by Telescope Support. Latest mappings are kept on the `wiyn-wttm` computer as `.forward` and `.reverse` files.

4.3 Acquiring an Object

4.3.1 Setting Initial Parameters
These parameters will usually achieve most of the performance gains the WTTM has to offer.

The control parameters are set from the wttmControlVI panel. Figure 3 WTTM Control GUI shows the panel with some typical values used for the parameters. The milligains, focus and guider intervals can be changed any time, and changes are activated by Set Parameters. To change any of the frequencies, first change its value in the box, then hit Stop Acquisition followed by Set Parameters. Then you are ready to Start Acquisition again.
Table 4-3 Default Control Values – APD Normalization Constants gives a more general listing of the current recommended default values.

Table 4-3 Default Control Values – APD Normalization Constants

<table>
<thead>
<tr>
<th>Property</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
</tr>
</thead>
<tbody>
<tr>
<td>APD0</td>
<td>2260</td>
<td>1831</td>
<td>1643</td>
<td>1461</td>
<td>1456</td>
<td>1371</td>
</tr>
<tr>
<td>APD1</td>
<td>869</td>
<td>881</td>
<td>913</td>
<td>874</td>
<td>876</td>
<td>899</td>
</tr>
<tr>
<td>APD2</td>
<td>565</td>
<td>661</td>
<td>704</td>
<td>779</td>
<td>793</td>
<td>817</td>
</tr>
<tr>
<td>APD3</td>
<td>1614</td>
<td>1253</td>
<td>1147</td>
<td>1127</td>
<td>1097</td>
<td>1077</td>
</tr>
<tr>
<td>APD/DIO Frequency = ν</td>
<td>50-1000 Hz</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>APD/DIO Update</td>
<td>10 Hz</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>X/Y Milligains = G_x/y</td>
<td>100-5 (Higher ν → Lower G)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Guider Interval = τ_g</td>
<td>5 s</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Focus Interval = τ_f</td>
<td>30 s</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Z Milligain = G_f</td>
<td>Consult observing support</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

4.3.1.1 APD/DIO Frequency

The APD/DIO frequency is the rate at which the APDs are read. An APD/DIO frequency of 200 Hz is a good point to start once you are at a star. Try to bring the APD counts into the 10-20 above background range for each APD. Increasing the APD/DIO frequency will reduce the counts and vice-versa.

Frequencies lower than 50 are still useful in order to compensate for coherent motion, such as wind shake, although less useful for “true” tip-tilt corrections.
4.3.1.2 APD/DIO Update Rate
The APD/DIO update rate is the rate at which the GUI updates. An APD/DIO update rate of 10-20 Hz should be fine. It is planned that this will soon be “hardwired” into the program, not left as a user option.

4.3.1.3 X and Y Gain
The X and Y milligains are measures of how much correction will be made for a given value of tip-tilt. At low APD/DIO frequencies you will need a larger value of gain to correct for image motion. Keeping the X and Y milligains to 50-75 for APD/DIO frequencies between 50 and 200 Hz is reasonable. For higher frequencies (between 500 and 1000) a lower value of 5 or 10 should be used. Setting these gains to 0 and Set Parameters will disable the tip-tilt. At present setting these gains to 0 does not stop telescope guiding. Therefore, it is strongly recommended that the user set the Guider Interval value to 0 at the same time as this does disable guiding.

4.3.1.4 Guider Interval
The Guider Interval is how often the WTTM sends tracking corrections to the telescope control system. This is sometimes referred to as “slow” telescope guiding. It is recommended that the user set the Guider Interval to 5s. The conversion from XY error signal to telescope Az/El corrections is controlled via the XY milligain conversion.

A low-pass guider signal is passed to the telescope control computer. The low-pass corrections ensure that the tip-tilt mirror of WTTM is centered and not biased towards one edge of its range of tip-tilt.

4.3.1.5 WTTM Auto Focus
Getting the focus of the telescope correct and keeping it correct is extremely important to the performance of the WTTM. Degradation of the focus will rapidly offset ALL of the gains that the Tip-Tilt correction provides.

At present it is recommended that the observer uses the auto-focus that the operator controls in the IAS rather than the WTTM auto-focus due to ease/difficulty of efficient operations. The available field for focus stars with the IAS probe is shown below.
On setup, one will want to confirm that the closed-loop control for focus tracking is off. This is done via the WTTM cli by typing:

```
% wszl -l0
```

Once confirmed off, you will need to set the Z milligain and the Focus Interval. Once the telescope is at the desired focus, focus error tracking is enabled and the system will automatically sense and track telescope focus based on the initial telescope focus. Therefore, it is important to establish the “best” focus for the WTTM detector before closing the focus loop.

**NOTE:** The WIYN port has a separate focus error sensing capability. It is important that you verify with the WIYN OA that the WTTM focus sensor is enabled, and that the WIYN port autofocus sensor is disabled. The OA also needs to ensure that the ARCON has privileges to change the focus. If the user notices that the focus shown on the SSD is not changing during a focus run check with the OA that both the WTTM and Instr are selected on their SecTilt GUI.

### 4.3.1.5.1 Focus Gain

If the seeing is not very good (say ~1 arcsec or higher), the Z milligain should be high (around 1000). When the seeing is quite good (0.6 arcsec or lower), even a value of ~500 should be good.

### 4.3.1.5.2 Focus Interval

Errors in telescope focus are tracked at a sample rate chosen via the Focus Interval. The recommended setting for Focus Interval is 30s in modal seeing of 0.7” or better and
stable conditions. Longer intervals should be used if focus error signal is noisy or seeing is highly variable.

4.3.2 First Focus
When the OA tells you that the telescope is pointed at the desired target do a quick focus sequence. The purpose of this focus is simply to select the correct range when you do a subsequent fine focus with the tip-Tilt enabled. When you take a focus frame with ARCON software at WIYN, you typically take a short (3-10s) exposure of a 11-12th magnitude star, clock the charge down 30 rows, decrease the focus value, take another exposure, clock down the charge, decrease the focus, etc., for a series of 7-9 exposures. The frame is then read out and the image examined with mscexam/mscfocus to determine the best focus value.

NOTE: The double-space marks the beginning of the sequence.

If the field is sparse enough the user can select a guide star based on the position of the last position of the field in the sequence.

4.3.3 Locking on a Guide Star
Observer should be able to use the LAST position of a focus sequence as the current location of the desired guide star. When acquiring the focus frame and/or test frame to locate a guide star the user should ensure that the tip/tilt mirror is at its nominal position and the x and y milligains are set to zero.

If the user cannot use the “first focus” frame to select a guide star then take a test exposure

cl> test

Select a fairly bright star (m, between 10 and 15) near your object of interest. In the IRAF Reduction Window type:

cl> mscexamine

The cursor will start to blink on the Ximtool window. Position the cursor on the star and type a to get its coordinates written in the Data Reduction Window.

Make sure that the APD power is on and that the acquisition has been started. Type the coordinates chosen in the XyManVI GUI and click on the Go button. When the XY stage for the error sensor gets to the selected position the user should see the counts on at least one of the APD’s rise fairly sharply. The lower the APD frequency is set the more obvious this rise will be.

Once the user has counts in at least one APD then the X and Y milligains and the Guider Interval may be set to non-zero values and the parameters set. Try to adjust the APD frequency so that the counts in each APD are approximately 10-20 above background. This will allow the WTTM to correct for the largest frequency bandwidth. It is possible to utilize Tip-Tilt with signal in the APDs up to several thousand counts, but if the APD frequency is less than 700 and counts in the APDs are high then the performance of the WTTM would be improved by increasing the APD frequency. Remember that to change
the APD frequency the acquisition must be stopped, the frequency changed, parameters set and then acquisition turned on again.

4.3.4 Fine Tuning Focus

Once the WTTM is set up and Tip-Tilt corrections are being made the observer should take another focus sequence with small increments (10 or even 5 micron increments). Since WTTM tries to extract the maximum seeing, it is crucial to focus it very accurately before starting.

4.3.5 Locking Auto Focus

Request the WIYN OA to set the telescope focus to the best focus, and then wait at least one “focus interval” (default is recommended as 30s) and lock the focus using the command:

```
[wttm@wiyn-wttm wttm]$ wszl -l1
[1 locks, 0 unlocks]
```

Verify the Z milligain and Focus Interval. This command may be given while acquisition is on-going.

At the point when the focus sensor is locked the algorithm uses the previous focus interval as the baseline reference for best focus.

The focus error signal that is present in the focus interval directly preceding locking the focus is used as the target value for subsequent, closed-loop corrections. WTTM will actively correct the telescope focus based on the deviation of the focus error signal from the target value. This target value frequently is non-zero. The focus error signal graph is in the top-right corner of the GetTaskValues GUI. Possibly easier to interpret are the graphs on the Focus GUI. The graph in the bottom-right corner of this GUI shows the corrections to focus being sent to the TCS by WTTM.

Setting a focus interval of ~30s is recommended for most purposes under reasonable seeing (0.7-1.0 arcsec). For worse seeing you may increase it and vice-versa.

4.3.6 Things to watch

4.3.6.1 Tip-tilt performance

If the tip-tilt is working properly, you should get 10-20 counts above background in each APD. The counts in all the APDs should be nearly balanced. The errors for all three X, Y and Z axes should be scattered randomly, the X and Y errors should be centered close to zero the Z error will likely not be centered around zero. Any increasing/decreasing trend in time points towards something going wrong. Usually we look at the “Raw APD errors” rather than the “Accumulat ed” errors because the accumulated errors average over an interval of time, whereas the raw errors are snapshots of errors in the APDs take after a fixed time.

Try to adjust the APD frequency, X and Y milligains and the Guider Interval to create the “tightest” pattern of errors around the zero point for both X and Y. Likewise with the Focus Interval and Z milligain. Attempt to create the tightest pattern around the, likely, non-zero value which is the value of the focus error signal with the telescope in focus.
This may be tricky since the user will first have to determine what value of focus error corresponds to the best telescope focus.

4.3.6.2 Guiding

The guide signals also should be small and randomly scattered around zero. Any observed trend points towards the fact that either the APDs lost the star (the counts should go down in wttmGetTaskValuesVI panel), maybe due to clouds, or the image motion is too large to compensate for (try increasing the X and Y milligains and reducing APD/DIO frequency).

4.3.6.3 Focus

As intuitively expected, the changes of the focus sent to the telescope should also be small and randomly scattered around zero when the focusing is working properly (and the temperature is not changing). However, the error values are based on the amount of astigmatism seen at the error sensor when the image at the science detector is in focus. This amount of astigmatism will generally be some non-zero value. The focus algorithm will then send focus corrections based on deviations from the non-zero datum.

Coma, as delivered by the telescope optics, has a first order effect on the focus signal and will dilute or bias the astigmatic signal. It is therefore essential that a good wavefront result be obtained prior to using the WTTM focus algorithm.

Known focus offsets between filters:

R = 0 by definition
I = 0±2 µm
B = +20±5 µm

4.3.7 To move to a new field

Once you are done with a particular field and want to move to another field, open the loop by setting the X and Y milligains and the Guider Interval to 0. Then unlock the focus with the command:

\[ \text{wiyn-wttm} > \text{wszl -l0} \]

Now you are ready to request the WIYN OA move the telescope to your next field. After getting to the next field, repeat the steps in sections 4.3.2 First Focus, to 4.3.6 Locking Auto Focus.

If the conditions are stable and the telescope is delivering coma free images it is possible to simply set the z milligain to zero move the telescope, acquire a guide star and reset the z milligain to a non-zero value to get the telescope into focus at the new field. If this is done the focus should **not** be unlocked with the wszl command.

4.4 Shutting down the WTTM System

When you are done using WTTM for the night, turn the X and Y milligains and Guider Interval to 0, unlock the focus and power the APDs off with the commands:

\[ \text{wiyn-wttm} > \text{wszl -l0} \]
You may want to shut the software down by issuing the command:

```
wiyn-wttm> wlv stop
```

This will close all the GUIs pertaining to controlling WTTM except xyManVI. To close xyManVI, click the **STOP** button, then go to the File menu and choose ‘Quit’. 
Chapter 5 Data Reduction

5.1 Calibration Data

Before/after the science exposures, the observer should take some calibration data for the CCD. This involves taking dome/sky flats, biases and darks. To take the dome flats you will need to arrange with either your OA or the daytime staff to set up the telescope for you. Once set up you should right click anywhere on the desktop on Navajo and select the Domeflat menu item. Once the GUI comes up, turn the high lamp on at your selected intensity (See Appendix 3: Dome Flat Settings). Once the lamps are set to an intensity of 500 or greater you should be able to see light on the dome camera by selecting channel #9 on the video switcher.

5.1.1 Zeros/Biases

You may take biases either using the zero or observe command in a Data Acquisition Window. Usually 5-10 biases per night.

5.1.2 Darks

5.1.3 Dome/Sky Flats

You may take flats either using the dflat, sflat or observe command in a Data Acquisition Window. Usually 5 through each filter with count levels of ~20,000 ADUs should be sufficient.
Chapter 6 DATA HANDLING

Right now the DAT tape drive is mounted on Sand. So the observer has to ftp all his data to Sand if DAT tapes are to be used. Both Exabytes and DATs are available. These are mta from the Exabyte and mtb is the DAT drive. The DAT supports DDS-4 densities (20 Gbytes per tape). The DAT on Sand is internal to the tower box while the Exabyte is external. Because of the multiextension format of WTTM data (although actually it is only a single CCD with one amplifier), you must use the IRAF mscwfits and mscrfits commands. To use the DAT drive type

\texttt{cl> allocate mtb}

from Sand. The parameters for mscwfits are shown in ^figure reference^. In order to check to see what is on the tape, you can list the titles quite easily. In an IRAF window on Sand simply type:

\texttt{cl> mscrfits mtb 1-999 list+ short+ original+}

To direct this output into a file, you can add a \texttt{>tapelist} to the end, and then you can print that list on the lineprinter by a simple \texttt{lprint tapelist}.

NOTE: If you do write additional files to an “old tape” (one containing useful data but which had previously been removed from the drive), make certain that the software (IRAF and Unix) is a ware that the tape has been rewound before starting to write to the tape – or your old data may be overwritten! To safeguard against this possibility we suggest that you ALWAYS swap tapes by first:

\texttt{cl>deallocate mtb}

Physically swap tapes.

\texttt{cl>allocate mtb}

6.1 SAFE TAPING

We recommend the following “safe taping” procedures.

- Each night write data to tape.
- Read the tape: \texttt{cl> mscrfits mtb list+} to substantiate everything is there.
- Deallocate the drive, remove the tape, and stick it under your pillow.
- Make a second copy of your tape. (This tape could be a cumulative copy of the data throughout your run.) Check this tape with mscrfits!
- Only now delete the data from disk if necessary.

6.2 SAVE THE BITS

All data taken at WIYN (and the other Kitt Peak telescopes) are automatically saved to tape. Extracting a night’s worth of data from these tapes is extremely labour-intensive, and we strongly emphasize the need for the “safe taping” procedures in section 6.1 Safe Taping. But, if you ever do need to recover a night’s worth of data, take heart! You can send email to kpno@noao.edu.
6.3 DAT
~?? Images/tape at DDS2/3/4. Write time is ~??s/image. 10.58Mb/image

6.4 EXABYTE
~?? images/tape. Write time is ~??s/image.

6.5 DLT
DLT-7000 (~?? images/tape) are also available. Write time is ~??s/image.

6.6 CD
You can take your data home on CDs, but, be forewarned, you will need about 4-5 CDs per night of observing. They hold only about 650 Mb of data (~60 images). Instructions from writing CDs can be found at [http://claret.kpno.noao.edu/wiyn/cd_write.html](http://claret.kpno.noao.edu/wiyn/cd_write.html). You should use the CD writer on Sand rather than Pearl; otherwise the instructions may not work. You can check the CDs by placing then in the CD reader on Sand and displaying from the directory /mnt/cdrom.
Chapter 7 APPENDIX 1: PERFORMANCE CHARACTERISTICS

The correction of atmospherically induced image motion is best for the guide star and degrades as a function of angular distance from the star. The region over which there is improvement over the static seeing conditions is known as the isoplanatic patch. The size of the isoplanatic patch is not well understood at this time, but it clearly will vary with atmospheric conditions. (if included add a reference to C. Claver’s paper on the subject) Also the graphs that Charles obtained with the latest T&E data.

![Graph showing FWHM vs Distance from Guide Star](image)
Chapter 8 Appendix 2: CLI Commands

CLI Command List? wiyn-wtm commands?
<command> help gives options

Main commands:
wcli – command line interface
wf – focus interface
wg – guider interface
wlv – LabVIEW interface
ex: wlv start|stop

Memory Dump Commands:
wda [0123] – dumps apd [0123]
wd [xyz] – dumps [xyz] error
wdd [xy] – dumps dio [xy]
wdl [xy] – dumps lva [xy]
wkg [xy] – dumps g[xy]err
wdfz – dumps fzerr

Status Commands:
wh – this help page
wgr – get real time values

System Commands: use <command> -h for help
wpw – sets power state
wsd – sets datum
ex: wsd –x0 –y0 –z0 –d0
wsfi – set focus interval
wsz – set focus target
ex: wszl –11|-10
wszo?0?, wszt
wsg – set gain
wsi – set integrator
wsgi – set guider interval
wsv – set voltage
ex: wsv -x0 -y0

Task Commands: use <command> -h for help
wstc – sets task cpus
wstf – sets task frequencies
wsts – sets task simulation flag
wstu – sets task update rates
wp – pause tasks
wr – resume tasks

????? wttm_pwr apd on/off ????
# Chapter 9 Appendix 3: Dome Flat Settings

## Table 9-1 Dome Flat Settings - Gain Setting 3

<table>
<thead>
<tr>
<th>Filter</th>
<th>Beam Splitter</th>
<th>Exposure Time (seconds)</th>
<th>Lamp Setting (high unless noted)</th>
<th>Counts</th>
</tr>
</thead>
<tbody>
<tr>
<td>Kron B</td>
<td>50/50</td>
<td>10</td>
<td>2500</td>
<td>30,000</td>
</tr>
<tr>
<td>Kron V</td>
<td>50/50</td>
<td>5</td>
<td>2000</td>
<td>24,000</td>
</tr>
<tr>
<td>Johnson R</td>
<td>50/50</td>
<td>5</td>
<td>1500</td>
<td>31,000</td>
</tr>
<tr>
<td>Cousins R</td>
<td>50/50</td>
<td>5</td>
<td>1000</td>
<td>23,000</td>
</tr>
<tr>
<td>Kron I</td>
<td>50/50</td>
<td>10</td>
<td>1000</td>
<td>35,000</td>
</tr>
<tr>
<td>Sloan Z</td>
<td>50/50</td>
<td>5</td>
<td>1000</td>
<td>19,000</td>
</tr>
<tr>
<td>SII - 6737</td>
<td>50/50</td>
<td>5</td>
<td>3200</td>
<td>37,000</td>
</tr>
<tr>
<td>H(\alpha) - 6575</td>
<td>50/50</td>
<td>5</td>
<td>3200</td>
<td>37,000</td>
</tr>
<tr>
<td>OIII</td>
<td>50/50</td>
<td>20</td>
<td>3200</td>
<td>18,000</td>
</tr>
<tr>
<td>Kron V</td>
<td>85/15</td>
<td>10</td>
<td>1630</td>
<td>30,000</td>
</tr>
<tr>
<td>Harris V</td>
<td>85/15</td>
<td>5</td>
<td>1750</td>
<td>21,000</td>
</tr>
<tr>
<td>Harris I</td>
<td>85/15</td>
<td>4</td>
<td>1000</td>
<td>23,000</td>
</tr>
<tr>
<td>Harris B</td>
<td>85/15</td>
<td>5</td>
<td>2500</td>
<td>22,000</td>
</tr>
<tr>
<td>Harris R</td>
<td>85/15</td>
<td>3</td>
<td>1500</td>
<td>24,500</td>
</tr>
<tr>
<td>Sloan Z</td>
<td>85/15</td>
<td>5</td>
<td>900</td>
<td>20,000</td>
</tr>
</tbody>
</table>

## Table 9-2 Dome Flat Settings - Gain Setting 1

<table>
<thead>
<tr>
<th>Filter</th>
<th>Beam Splitter</th>
<th>Exposure Time (seconds)</th>
<th>Lamp Setting (high unless noted)</th>
<th>Counts</th>
</tr>
</thead>
<tbody>
<tr>
<td>Kron B</td>
<td>85/15</td>
<td>5</td>
<td>3200</td>
<td>22,750</td>
</tr>
<tr>
<td>Kron V</td>
<td>85/15</td>
<td>5</td>
<td>2200</td>
<td>20,000</td>
</tr>
<tr>
<td>Kron I</td>
<td>85/15</td>
<td>5</td>
<td>1200</td>
<td>21,000</td>
</tr>
<tr>
<td>Johnson R</td>
<td>85/15</td>
<td>5</td>
<td>1600</td>
<td>21,300</td>
</tr>
<tr>
<td>Sloan Z</td>
<td>85/15</td>
<td>5</td>
<td>1200</td>
<td>19750</td>
</tr>
</tbody>
</table>
Chapter 10  Appendix 4: Startup Checklist

10.1 Telescope Floor & Level B

1. Check mask
2. Check filters
3. Check beam-splitter
4. Check aperture wheel setting
5. Power on APD Chassis and PI Chassis (white plastic switch)
   a. white plastic switch
   b. should see orange light near switch
   c. should see green lights on PI chassis
6. Power on Filter/Shutter box
   a. silver toggle switch on gray box – down is on
7. Power on XY Chassis

10.2 Sand & wiyn--wttm

1. Login to almond as observer
   a. usual mountain password
2. Start an xterm if necessary
3. ssh to wiyn-wttm as wttm
   a. ssh wttm@wiyn-wttm
4. wlv start
5. xyManVI &
   a. initialize
   b. calibrated mode
   c. use previous
   d. if necessary choose correct db files
6. arrange various GUI windows
7. Set standard starting values
   a. APD freq. = 200
   b. DIO freq. = 200
   c. APD update = 10
   d. DIO update = 10
   e. Focus interval = 30
   f. Guider interval = 1-5
   g. XY milligains = 0
   h. Z milligain = 500-1000 – based on seeing (better seeing smaller gain)
   i. APD0 milligain = 1380
   j. APD1 milligain = 886
   k. APD2 milligain = 814
   l. APD3 milligain = 1089
8. Check APD status
   a. Setup for dome flats
   b. Start acquisition
   c. wttm_pwr apd on
   d. wttm_pwr apd off
10.3 NAVAJO

1. Login as wiyn_ccd
   a. usual mountain password
2. Arcon and data reduction window should start
   a. if ARCON doesn’t start try starting from background menu
   b. if Data Reduction window doesn’t start try:
      i. start an xgterm
      ii. cd /data0/wiyn_ccd/reduce
      iii. cl
3. Check Wheel1
   a. motor init if necessary
4. setup/change to correct directory
5. DCA Edit menu – no preprocessing

10.4 FIELD ACQUISITION

1. Slew to field – operator
2. Check pointing – operator
3. Take coarse focus
4. Set focus – operator
5. Take test if necessary
6. Determine position of Tip-Tilt star
7. Ensure that the Tip-Tilt mirror is in its nominal position (stop/start acquisition or wsv/wsd
   commands)
8. Find Tip-Tilt star and start Tip-Tilt and guiding (xy milligains and guider interval to non-zero)
9. Take fine focus
10. Set focus – operator
11. It may be best at this point to stop and start acquisition since this will ensure that all values are
    zeroed.
12. Pause for at least one Focus Interval
13. Lock focus (wszl –I)
14. Observe
Chapter 11  PHOTOMETRY DEMONSTRATION

11.1 WTTM & 85/15 BEAM SPLITTER

Abi Saha

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On the night of UT 030516, several Landolt standard fields were observed with the WTTM, in the B,V,R,I passbands. The 85/15 beam splitter was in use. The standard star observations were processed in the usual way, and photometric solutions were obtained for this night, solving for atmospheric extinction, as well as color terms.

Let $b_p$, $v_p$, $r_p$ and $i_p$ be the instrumental magnitudes in the B,V,R,I pass bands respectively. These are of the form:

$$x_p = -2.5 \cdot \log_{10}(DN) + 30.00$$

where $DN$ is count rate from a star in Data numbers, analog to digital units in passband $x$ then, we can write:

$$M_{True} = x_p + C_0 + C_1 \cdot X_{airmass} + C_2 \cdot \alpha_p$$

where $M_{True}$ is the true magnitude, $x_p$ is the instrumental magnitudes, $C_0$ the zero-point constants, $X$ the airmass, and $\alpha_p$ the instrument color terms, like $v_p-i_p$, $v_p-r_p$, etc.
The solution for the night of UT030516 are then the coeffs $C_0$, $C_1$, and $C_2$ which were determined for all filters and all possible color combinations. The full solution is given immediately below:

**UT 030516  WTTM  85/15 beam splitter**

<table>
<thead>
<tr>
<th>Passband</th>
<th>$\alpha_p$</th>
<th>$C_0$</th>
<th>$C_1$</th>
<th>$C_2$</th>
<th>Rms$_{res}$</th>
<th>Err$_{mean}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>V</td>
<td>$b_p-v_p$</td>
<td>-4.548</td>
<td>-0.178</td>
<td>-0.148</td>
<td>0.012</td>
<td>0.003</td>
</tr>
<tr>
<td>V</td>
<td>$v_p-r_p$</td>
<td>-4.593</td>
<td>-0.170</td>
<td>-0.176</td>
<td>0.021</td>
<td>0.005</td>
</tr>
<tr>
<td>V</td>
<td>$v_p-i_p$</td>
<td>-4.603</td>
<td>-0.193</td>
<td>-0.089</td>
<td>0.020</td>
<td>0.005</td>
</tr>
<tr>
<td>B</td>
<td>$b_p-v_p$</td>
<td>-4.434</td>
<td>-0.386</td>
<td>0.208</td>
<td>0.019</td>
<td>0.005</td>
</tr>
<tr>
<td>B</td>
<td>$b_p-r_p$</td>
<td>-4.418</td>
<td>-0.379</td>
<td>0.109</td>
<td>0.022</td>
<td>0.006</td>
</tr>
<tr>
<td>B</td>
<td>$b_p-i_p$</td>
<td>-4.387</td>
<td>-0.371</td>
<td>0.076</td>
<td>0.021</td>
<td>0.005</td>
</tr>
<tr>
<td>R</td>
<td>$b_p-r_p$</td>
<td>-4.889</td>
<td>-0.016</td>
<td>-0.053</td>
<td>0.017</td>
<td>0.005</td>
</tr>
<tr>
<td>R</td>
<td>$v_p-r_p$</td>
<td>-4.902</td>
<td>-0.016</td>
<td>-0.115</td>
<td>0.017</td>
<td>0.005</td>
</tr>
<tr>
<td>R</td>
<td>$r_p-i_p$</td>
<td>-4.920</td>
<td>-0.043</td>
<td>-0.117</td>
<td>0.018</td>
<td>0.005</td>
</tr>
<tr>
<td>I</td>
<td>$v_p-i_p$</td>
<td>-5.338</td>
<td>-0.107</td>
<td>-0.019</td>
<td>0.011</td>
<td>0.003</td>
</tr>
<tr>
<td>I</td>
<td>$b_p-i_p$</td>
<td>-5.334</td>
<td>-0.106</td>
<td>-0.012</td>
<td>0.011</td>
<td>0.003</td>
</tr>
<tr>
<td>I</td>
<td>$r_p-i_p$</td>
<td>-5.362</td>
<td>-0.097</td>
<td>-0.041</td>
<td>0.011</td>
<td>0.003</td>
</tr>
</tbody>
</table>

Rms residuals are 0.02 mag or less, which is typical of a clear (but not pristine photometric) night. The extinction coefficients are also typical of a clear night, but on pristine nights they are up to 30% smaller.

**WTTM Count Rates & MiniMo**

For a star of zero intrinsic color and $B=V=R=I=20.0$, we can surmise the count rate in photons per second from the above, given that the `gain' was set to 1.33 electrons per DN. These rates are derived to be:

<table>
<thead>
<tr>
<th>Passband</th>
<th>WTTM Count rate (photons/s)</th>
<th>MiniMo Count rate (photons/s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>B</td>
<td>221</td>
<td>284</td>
</tr>
<tr>
<td>V</td>
<td>205</td>
<td>295</td>
</tr>
<tr>
<td>R</td>
<td>150</td>
<td>321</td>
</tr>
<tr>
<td>I</td>
<td>97</td>
<td>170</td>
</tr>
</tbody>
</table>

On the night of UT030602, a similar calibration was done with MIMO, with a `gain' setting of 1.4 electrons per DN. This night was only 21 nights after the WTTM data discussed above -- and the telescope mirrors and optics can be assumed to be in an equivalent state for reflectance and scattering. Thus, a comparison of count rates between the MIMO results of UT030602 with WTTM results from UT030516 is meaningful comparison of throughput.
The count rates derived from MIMO observations on UT030602 (for a star with B=V=R=I=20.0 mag) are included in the table above.

Thus the comparative throughput in WTTM$_{85/15}$ vs MIMO are:

- 0.78 in B
- 0.69 in V
- 0.47 in R
- 0.57 in I

These differences INCLUDE the effect of the extra reflections to get the light into WTTM, as well as the reflections within the WTTM. They also reflect any passband and filter throughput differences.