WASP
A new wafer scale imaging camera for the Palomar Observatory 2018

E2V 6144x6160 CCD231-C6 Back Illuminated Science Detector
Two STA3600A 2064x2064 Guide and Focus Detectors
Jennifer W. Milburn February 7, 2018
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</table>
Quick Start Guide

• Open the following vnc desktop on the observer computer (vncviewer 198.202.125.140:16)
• Right mouse click on the desktop and select open terminal.
• Start the WASP instrument control software by typing “wasp”
• Open the “WASP Filter-wheel and Shutter Control”
• “Home” the shutter first
• “Home” the filter-wheel
• Select filter you wish to focus in.
• Open the “Electronics Monitoring” tab and engage “Activate Shutter” and “Activate Filter-wheel”
• Select “LFC Shutter” radiobutton.
• Return to the main panel and engage the “Display in DS9” button
• The WASP software is now ready to take images
Taking BIAS frames:
- The easiest way to take bias frames is to set the exposure time to 0 seconds.
- Deactivate the shutter so that it doesn’t open ("Activate Shutter" icon should be red not green on the "Electronics Monitoring" tab).
- Engage the "continuous" button so that it turns from grey to green (to the right of the “GO” button)
- Press “GO” and then wait for the desired number of frames to be taken.
- Disengage the “continuous” button so that the system stops taking frames after the desired number have been taken.
- IMPORTANT: Remember to “Activate Shutter” after the finishing your bias frames.

Taking FLATS
- The easiest way to take flats is to run a script “flats.txt” that will take 10 images in each of the 4 filter positions.
- Open the “WASP Script Execution” control.
- Select the “File” button and open the “flats.txt” script.
- Select the “Script Editor” panel
  - edit the filter names and the output BASENAME for each filter. Be careful with the filter names, they must exactly match the names in the filter GUI
  - Ask the support astronomers for the recommended exposure times and lamp settings for your filters. Edit the exposure time for each filter
- Press the “Parse Script File” so that the commands table is updated
- Press the “GO” button on the “WASP Script Execution” control
- Go the dinner 😊

Reducing the calibration frames
- IRAF is installed on the WASP computer and is the typical tool for reducing WASP data.
- Use imcombine with combine=median to create a master bias frame.
- Use imarith to subtract the master bias from each of the flat field images.
- Use imcombine to combine the flat field images after the bias has been subtracted using combine=median, scale=mode
- Run imstat on the combined image to calculate the mode.
- Normalize the combined flat field image by using imarith and divide the image by the mode.
- Note: you can remove the prescan from a WASP image with `imcopy $filename[51:6194,1:6160] $new_filename` for images without overscan.
Quick Start Guide –continued
When your first On-Sky

- **Establish telescope pointing**
  - When you’re first on-sky you need to set the telescope pointing so that a requested target star falls directly in the center of the science detector. This is important so that the preliminary WCS in the images is essentially correct.
  - Request that the telescope operator select a bright SAO star near zenith. The star simply needs to be bright enough so that you can easily identify the star in the image.
  - Take a short exposure time image (1 to 10 seconds) and examine where the star lies in the science detector field.
  - Use the “Target to Bullseye” function to move the star to the center of the detector.
    - Right mouse click on the image and select the “Target” cursor. Place the target cursor on the SAO star.
    - Right mouse click on the image and select the “Bullseye” cursor. Place the bullseye cursor at the center of the science detector.
    - Verify that the delta RA and delta Dec below the “Move Target to Bullseye” button are reasonable.
    - Press the “Move Target to Bullseye” button and then wait for the progress bar to indicate that the move is complete.
  - Take a new image and verify that the SAO star is now at the center of the science detector.
    - If the SAO star isn’t in the exact center of the field then repeat the previous step with “Target to Bullseye”.
Quick Start Guide – continued
When your first On-Sky – Calibrating the WCS

- The image above displays the overlay of the UCAC3 catalog on the image. Note that the stars obviously don’t line up correctly.
- It’s relatively easy to visualize that the catalog is shifted to the North and West (up and to the right) relative to the image.

- Adjust the CRPIX1 and CRPIX2 keywords until the stars in the catalog obviously line up with the stars in the image.
- Since distortions are greatest near the lower right corner it’s best to line up stars in the middle of the field and to allow the distortion polynomials to take care of the correction.
Quick Start Guide –continued

Focusing the the telescope

• Focus the telescope
  – If the WASP instrument has just been installed you need to run a complete
    focus increment set of observations and then analyze the results
    • Open the “WASP Script Execution” control and then open the
      “focus2.txt” script. This script will take 20 images at focus increments
      of 0.1mm starting at a value below best focus. (ask the support
      astronomer if the script has been updated to take a smaller number of
      images)
    • Run the focus script to create the 20 images
    • Open the “Sexttractor” control and press the “Focus Graph Analysis”
      button to open the control
    • Select the files created by the script by pressing the “Select File”
      button and browsing for the files.
    • Press “Process” and wait for the analysis to complete.
    • Determine the minimum focus position from the “Median” focus donut
      graph (left red curve), verify that it matches with the minimum of the
      FWHM graph (right).
    • Tell the telescope operator to set focus to the measure valu
  – If this isn’t the first night of a WASP install then you can use the
    “Quick Focus” tool to determine focus.
    • Ask the telescope operator what the focus was the last time the instrument was
      used and enter that value into the “Estimated FOCUS” field
    • Ask the support astronomer for the current best known value of ALPHA and
      enter it into appropriate field
    • Set the “Offset in mm”. The nominal value for this is 1mm but it can range
      from 0.7 to 1.5mm. As the support astronomer for their advice on what the best
      value is for the offset.
    • Set the exposure time (typically 10 to 30 seconds)
    • Press “GO” on the Quick Focus control. The system will then take two images,
      one at the estimated focus minus the offset and the other at estimated focus
      plus the offset. The system will then run Sexttractor on both images and
      calculate the donut metric for each.
    • The estimated “BEST FOCUS” will be displayed.
    • Now enter the “BEST FOCUS” value into the “Estimated FOCUS” field and
      rerun the quick focus.
    • Check that the resulting donut metrics on the high and low side are close to
      identical.
    • Tell the telescope operator to set the focus to the “BEST FOCUS” value
      returned for the second run of the “Quick Focus”.
    • The instrument is now in focus.
Quick Start Guide –continued
Congratulations! You are now ready to do science!

• Summary:
  – Start the WASP software
  – Home the Shutter
  – Home the Filter Wheel
  – Operations in the afternoon once the dome is dark
    • Collect calibration frames
      – Collect BIAS frames and create a master BIAS frame
      – Run the “flats.txt” script to collect flat field images.
  – When you’re first on sky
    • Establish pointing with a bright SAO star
    • Focus the telescope
  • You’re DONE! It’s time to do science
FIRST LIGHT IMAGES
WASP hardware components ready for assembly
WaSP “Laboratory First Light” Image
E2V 6144x6160 CCD231-C6 Back Illuminated Science Detector
January 29, 2016
WASP First Light Images
February 29, 2016
CRAB Nebula (M1)
G’=green, R’=red, I=blue

18.43 arc minutes

18.48 arc minutes
WASP First Light Images
February 29, 2016
M51 and M52, NGC4038 – The Antennae Galaxies

COLLIDING GALAXIES

M51 and M52
Taken March 2016 Palomar Observatory by Jennifer Milburn
Processed by Justin Belicki

NGC 4038 The “Antennae Galaxies”
DS 9 Overlays G'=green, R'=red, I=blue
WASP First Light Images
December 31, 2017
M101 – The Pinwheel Galaxy
WASP – Palomar P200 Telescope
First Light Delta-Doped STA3600A Detectors
September 13, 2016

Colliding Galaxies – NGC 7674  G’ Band and U’ band

Colliding Galaxies – Stephen’s Quintet R’ Band
NGC 7318
WASP – Palomar P200 Telescope
First Light Delta-Doped STA3600A Detectors
September 13, 2016
Exposure Time = 100 seconds, U', G', R'

Colliding Galaxies – NGC 7674
G', R', and U'
G' = green, R' = red, U' = blue

Colliding Galaxies – Stephen’s Quintet
NGC 7318
G' = green, R' = red, U' = blue

Colliding Galaxies – NGC 7674

Colliding Galaxies – Stephen’s Quintet
NGC 7318

*Photoshop CC 2017 used to create color composites
DETECTOR CHARACTERISTICS

Left to right: Pavan Bilgi, Roger Smith and Alex Delacroix during assembly of the WASP focal plane
WASP Detector Characteristics Summary

- Summary of Detector Characteristics

<table>
<thead>
<tr>
<th>SCIENCE DETECTOR</th>
<th>GUIDE AND FOCUS DETECTORS</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>E2V CCD231-C6 Back Illuminated</strong></td>
<td><strong>STA 3600A delta-doped CCD</strong></td>
</tr>
<tr>
<td>number of pixels</td>
<td>6144 (H) x 6160 (V)</td>
</tr>
<tr>
<td>microns/pixel</td>
<td>15 um square</td>
</tr>
<tr>
<td>image area mm</td>
<td>92.2mm x 92.4mm</td>
</tr>
<tr>
<td>Image area arcminutes</td>
<td>18.43 arcminutes x 18.48 arcminutes</td>
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<tr>
<td>outputs</td>
<td>4</td>
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<tr>
<td>Readout Noise</td>
<td>5.0 e</td>
</tr>
<tr>
<td>full well capacity</td>
<td>350,000 e-</td>
</tr>
<tr>
<td>dark current</td>
<td>3 e-/pixel/hour</td>
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</tbody>
</table>

**Unique Features**

19.2 arcminutes squared frame transfer enabled autoguider

Autofocus using a dedicated focus detector ("Donut" method)

Simple scripting language to allow complete control of complex imaging sequences
WASP Detector Characteristics
Summary from Data Sheet

**SCIENCE DETECTOR**
E2V CCD 231-C6 Back Illuminated, Deep Depletion Device

**GUIDE AND FOCUS DETECTORS**
STA 3600A delta-doped* CCD

<table>
<thead>
<tr>
<th>SUMMARY PERFORMANCE (Typical)</th>
<th>FEATURES</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of pixels</td>
<td>6144(H) x 6160(V)</td>
</tr>
<tr>
<td>Pixel size</td>
<td>15 µm square</td>
</tr>
<tr>
<td>Image area</td>
<td>92.2 mm x 92.4 mm</td>
</tr>
<tr>
<td>Outputs</td>
<td>4</td>
</tr>
<tr>
<td>Package size</td>
<td>98.5 x 93.7 mm</td>
</tr>
<tr>
<td>Package format</td>
<td>Silicon carbide with two flexi connectors</td>
</tr>
<tr>
<td>Focal plane height, above base</td>
<td>20.0 mm</td>
</tr>
<tr>
<td>Height tolerance</td>
<td>±15 µm</td>
</tr>
<tr>
<td>Connectors</td>
<td>Two 37-way micro-D</td>
</tr>
<tr>
<td>Flatness</td>
<td>&lt;40 µm (peak to valley)</td>
</tr>
<tr>
<td>Amplifier sensitivity</td>
<td>7.5 µV/e⁻</td>
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<tr>
<td>Readout noise</td>
<td>5 e⁻ at 1 MHz</td>
</tr>
<tr>
<td></td>
<td>2 e⁻ at 50 kHz</td>
</tr>
<tr>
<td>Maximum pixel data rate</td>
<td>3 MHz</td>
</tr>
<tr>
<td>Charge storage (pixel full well)</td>
<td>350,000 e⁻</td>
</tr>
<tr>
<td>Dark signal</td>
<td>3 e⁻/pixel/hour (at −100 °C)</td>
</tr>
</tbody>
</table>

- 2064 x 2064 CCD Image Array
- 15 µm x 15 µm Pixel
- 30.96 mm x 30.96 mm Image Area
- Near 100% Fill Factor
- Readout Noise Less Than 3 Electrons at 100KHz
- 4 Single Stage 3MHz Outputs
- Three-Phase Buried Channel Image area
- Multi-pinned Phase (MPP)
- Three-Phase Buried Channel Readout Registers
- Selectable Video Output Channels
- Backside Illuminated

Operated as frame-transfer devices
With effective image area of 2064x1032 pixels

* delta-doped to enhance UV performance
WASP Detector Characteristics
E2V CCD 231-C6 Photon Transfer Curve

- The science detector is readout in quadrants with 4 separate amplifiers. The full well capacity and conversion gain for each quadrant are listed below.

![Photon Transfer Curve for each amplifier of the e2v detector.]

### Measured WASP Full well and Conversion Gain

<table>
<thead>
<tr>
<th>Quadrant</th>
<th>Full Well Capacity (e-)</th>
<th>Conversion Gain (e-/adu)</th>
<th>SATURATE (DN)</th>
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<tr>
<td>AD5</td>
<td>326000</td>
<td>5.9382</td>
<td>54898.4</td>
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<td>AD6</td>
<td>331000</td>
<td>6.0423</td>
<td>54780.5</td>
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<tr>
<td>AD7</td>
<td>330000</td>
<td>5.8445</td>
<td>56463.0</td>
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<tr>
<td>AD8</td>
<td>334000</td>
<td>5.8514</td>
<td>57080.6</td>
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<tr>
<td>Average</td>
<td>330250</td>
<td>5.919</td>
<td>55806</td>
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</table>
WASP Detector Characteristics
E2V CCD 231-C6 Linearity Curve

- Detector Linearity: Within 1% up to 45,000 ADU

Table of Linearity Measurements

<table>
<thead>
<tr>
<th>Exposure Time</th>
<th>Mean</th>
<th>Mode</th>
<th>Standard Deviation</th>
<th>Estimated Flux</th>
<th>Error ADU</th>
<th>Error %</th>
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<td>1.00</td>
<td>10207</td>
<td>10567</td>
<td>1331</td>
<td>10564.2</td>
<td>-2.8</td>
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<td>2.00</td>
<td>13422</td>
<td>13908</td>
<td>1752</td>
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<td>4.00</td>
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<td>20677</td>
<td>2608</td>
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<td>3037</td>
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<td>6.00</td>
<td>26515</td>
<td>27404</td>
<td>3466</td>
<td>27388.7</td>
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<td>-0.06</td>
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<td>7.00</td>
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<td>30868</td>
<td>3890</td>
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<td>40540</td>
<td>5166</td>
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<td>49423</td>
<td>17114</td>
<td>50943</td>
<td>1520.0</td>
<td>2.98</td>
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WASP Flat Field Calibration
Low and High Lamp flux in ADU/second

Optimal Flux for Flats: 60% full well
Full Well = 45000

<table>
<thead>
<tr>
<th>Low Lamp Flux Summary</th>
<th>1000</th>
<th>5000</th>
<th>10000</th>
<th>25000</th>
<th>50000</th>
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<tbody>
<tr>
<td><strong>G</strong></td>
<td>107.11</td>
<td>9.34</td>
<td>46.68</td>
<td>93.36</td>
<td>233.40</td>
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<tr>
<td><strong>I</strong></td>
<td>835.97</td>
<td>1.20</td>
<td>5.98</td>
<td>11.96</td>
<td>29.91</td>
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<tr>
<td><strong>R</strong></td>
<td>551.36</td>
<td>1.81</td>
<td>9.07</td>
<td>18.14</td>
<td>45.34</td>
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<td><strong>Z</strong></td>
<td>446.27</td>
<td>2.24</td>
<td>11.20</td>
<td>22.41</td>
<td>56.02</td>
</tr>
</tbody>
</table>

| High Lamp Flux Summary | | | | | |
|------------------------| | | | | |
| **G**                  | 6032 | 0.17 | 0.83 | 1.66 | 4.14  | 8.29  | 4.48 seconds |

Note: R', I' and Z' filters saturate in less than 1 second with the High Lamp

Recommended Exposure Time for Sloan Flats
Sloan Filter
- G' 4.48 High Lamp (seconds)
- I' 32.30 Low Lamp (seconds)
- R' 48.97 Low Lamp (seconds)
- Z' 60.50 Low Lamp (seconds)

(≈27,000 ADU)
WASP Detector Characteristics
E2V CCD 231-C6
Quantum Efficiency Curves

• The quantum efficiency as a function of wavelength for the WASP science CCD (black curve)
WASP Detector Characteristics
STA 3600 A 2064x2064 pixels CCD
Quantum Efficiency Curves

• The quantum efficiency as a function of wavelength for the WASP Guide and Focus CCD’s (without the delta-doping)
DECEMBER 31, 2017 HORSEHEAD NEBULA

WASP FILTERS
WASP Filters
Transmission Curves for WASP filters

• WASP uses the same filter-wheel employed by LFC so the entire set of LFC filters is available.

• [www.astro.caltech.edu/palomar/observer/200inchResources/lfcspecs.html](http://www.astro.caltech.edu/palomar/observer/200inchResources/lfcspecs.html)

<table>
<thead>
<tr>
<th>Filter</th>
<th>Central $\lambda$ (Å)</th>
<th>Width (Å)</th>
<th>Thickness (mm)</th>
<th>Focus offset (mm from $r'$)</th>
<th>Dome flats [a]</th>
<th>Dark sky [b] (raw chip 0°)</th>
<th>Transmission</th>
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<tbody>
<tr>
<td>$r'$</td>
<td>6255</td>
<td>1470</td>
<td>3.05</td>
<td>-</td>
<td>5</td>
<td>1400</td>
<td>data, plot</td>
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<tr>
<td>$i'$</td>
<td>7680</td>
<td>1540</td>
<td>3.05</td>
<td>-</td>
<td>3</td>
<td>650</td>
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<tr>
<td>$z'$</td>
<td>~9000</td>
<td>~1800 (w/eq)</td>
<td>3.05</td>
<td>-</td>
<td>5</td>
<td>750</td>
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<tr>
<td>$g'$</td>
<td>4680</td>
<td>1400</td>
<td>8.02</td>
<td>+1.5</td>
<td>40</td>
<td>data, plot</td>
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<tr>
<td>$u'$</td>
<td>3540</td>
<td>590</td>
<td>8.38</td>
<td>+1.6</td>
<td>120</td>
<td>highamp</td>
<td>data, plot</td>
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<tr>
<td>R6</td>
<td>6930</td>
<td>1220</td>
<td>10.26</td>
<td>+2.0</td>
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<tr>
<td>I6</td>
<td>8190</td>
<td>1670</td>
<td>10.26</td>
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<td>B-boss</td>
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<td>1000</td>
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<td>+1.3</td>
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<td>V-boss</td>
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<td>+1.3</td>
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<td>R-boss</td>
<td>6300</td>
<td>1200</td>
<td>7.0</td>
<td>+1.3</td>
<td>10</td>
<td>data, plot</td>
<td></td>
</tr>
<tr>
<td>I-boss</td>
<td>9000</td>
<td>3000</td>
<td>7.0</td>
<td>+1.3</td>
<td></td>
<td>data, plot</td>
<td></td>
</tr>
<tr>
<td>Broad-R1</td>
<td>7670</td>
<td>2940</td>
<td>6.0</td>
<td></td>
<td></td>
<td>data, plot</td>
<td></td>
</tr>
<tr>
<td>Hz</td>
<td>6570</td>
<td>100</td>
<td>11.68</td>
<td>+2.6</td>
<td>120</td>
<td>plot</td>
<td></td>
</tr>
<tr>
<td>S-II</td>
<td>6730</td>
<td>90</td>
<td>11.68</td>
<td>+2.6</td>
<td>120</td>
<td>plot</td>
<td></td>
</tr>
<tr>
<td>6610/100</td>
<td>6610</td>
<td>100</td>
<td>7.06</td>
<td>+1.3</td>
<td>120</td>
<td>plot</td>
<td></td>
</tr>
<tr>
<td>6650/100</td>
<td>6650</td>
<td>100</td>
<td>7.06</td>
<td>+1.3</td>
<td>120</td>
<td>plot</td>
<td></td>
</tr>
<tr>
<td>8700/100</td>
<td>8700</td>
<td>100</td>
<td>6.93</td>
<td>+1.3</td>
<td>120</td>
<td>plot</td>
<td></td>
</tr>
<tr>
<td>5200/70</td>
<td>5200</td>
<td>70</td>
<td>4.90</td>
<td>?</td>
<td></td>
<td>not yet on record</td>
<td></td>
</tr>
<tr>
<td>5085/70</td>
<td>5085</td>
<td>70</td>
<td>5.13</td>
<td>?</td>
<td></td>
<td>not yet on record</td>
<td></td>
</tr>
</tbody>
</table>

[a] Seconds to 10,000 DN (unbinned)
WASP Filters
Transmission Curves for WASP filters
Broadband Sloan Filters

Filter Transmission Curves
Broadband Sloan Filters

Wavelength (angstroms)

% Transmission

u'   g'   r'   i'   z'

R Prime  I Prime  Z Prime  G Prime  U Prime
WASP Filters
Transmission Curves for WASP filters
Narrow Band and Special Filters

Wavelength (angstroms)

% Transmission

B-BESS  V-BESS  R-BESS  I-BESS  IS-FILTER  BROAD-RI

IS Filter  BESS-B  V-BESS  R-BESS  I-BESS  BROAD-RI
WASP Filters
Transmission Curves for WASP filters
Narrow Band Filters

H-Alpha Filter

\[ \lambda = 6570 \text{ A} \]
\[ \text{Width} = 100 \text{ A} \]

Wavelength (angstroms)

S-II Filter

\[ \lambda = 6730 \text{ A} \]
\[ \text{Width} = 90 \text{ A} \]

Wavelength (angstroms)

6650/100

\[ \lambda = 6610 \text{ A} \]
\[ \text{Width} = 100 \text{ A} \]

Wavelength (angstroms)

6700/100

\[ \lambda = 6700 \text{ A} \]
\[ \text{Width} = 100 \text{ A} \]

Wavelength (angstroms)

6610/100

\[ \lambda = 6610 \text{ A} \]
\[ \text{Width} = 100 \text{ A} \]

Wavelength (angstroms)
WASP INSTALLATION
WASP Installation at prime focus of the Hale 200” Telescope at Palomar Observatory
February 28, 2016

WASP assembled with shutter and filter wheel ready to be lifted to prime focus

WASP being lifted by the crane to prime focus
WASP Installation at prime focus of the Hale 200” Telescope at Palomar Observatory
February 28, 2016

WASP being lowered into the prime focus cage

WASP installed and cabled – READY FOR OBSERVING!
WASP Installation at prime focus of the Hale 200” Telescope at Palomar Observatory
February 28, 2016

WASP installed and cabled – READY FOR OBSERVING!
WASP Installation Procedure

- WASP should only be installed in this orientation
The WASP Instrument
A Visual Tour

Network enabled power strip

LAKESHORE 330
Temperature controller

Lesker Pressure Monitor

High voltage supply
For the STA detector
back side bias

ARCHON electronics
Power supply

Motor Controller box for
the shutter and filter wheel

LN2 fill port

Vacuum port

LabJack enclosure –
reads the hall sensor states
for both shutter and filter
wheel

ARCHON VIB electronics
The WASP Instrument
The computer connections

- Computer Power Supplies
- Ethernet Cable to public network
- Eth1 Ethernet port
  NOT USED AT PALOMAR
- Adnaco USB to fiber interface card
  used for the USB to RS-232 port
  employed by the shutter and filter wheel
  (note fiber not inserted in the absence of
   the shutter and filter wheel at Caltech)
- Display port cable to monitor
- Archon fiber interface card
The WASP Instrument
How to tell that the shutter and filter-wheel are properly connected?

• First check that the USB 3.0 root hub shows up when you run “lsusb” in a terminal.
• 2nd check that the “Prolific Technology PL2303 Serial Port is present.
• As root, change the permissions on /dev/ttyUSB0 to rw (chmod a+rw ttyUSB0)
• If the USB 3.0 hub doesn’t show up; check that you have 2 green lights on the Adnaco (indicating correct fiber connection) then reboot the computer.

```
[developer@wasp2 ~]$ lsusb
Bus 001 Device 001: ID 1d6b:0002 Linux Foundation 2.0 root hub
Bus 002 Device 001: ID 1d6b:0002 Linux Foundation 2.0 root hub
Bus 001 Device 002: ID 8087:0024 Intel Corp. Integrated Rate Matching Hub
Bus 002 Device 002: ID 8087:0024 Intel Corp. Integrated Rate Matching Hub
Bus 001 Device 003: ID 062a:4101 Creative Labs Wireless Keyboard/Mouse
Bus 001 Device 004: ID 0557:2221 ATEN International Co., Ltd Winbond Hermon
Bus 003 Device 001: ID 1d6b:0002 Linux Foundation 2.0 root hub
Bus 004 Device 001: ID 1d6b:0003 Linux Foundation 3.0 root hub
Bus 003 Device 002: ID 067b:2303 Prolific Technology, Inc. PL2303 Serial Port
```

Adnaco USB to fiber interface card used for the USB to RS-232 port employed by the shutter and filter wheel

(note fiber not inserted in the absence of the shutter and filter wheel at Caltech)

The WASP computer has no native USB 3.0 hub on the motherboard so the presence of a USB 3.0 hub indicates that the Adnaco is correctly connected. The “Prolific Technology, Inc. PL2303 Serial Port” is the 25 pin serial to USB cable connected to the motor controllers for the shutter and filter-wheel.
WASP installation

• PRIME FOCUS CAGE INSTALLATION
  – WASP connections to the Palomar prime focus cages - 2 pairs of fiber
    • Optical fiber connections
      – Archon controller
      – Adnaco USB to fiber
    – Ethernet connection - 3 Ethernet connections
      • Two possible configurations: With Ethernet switch and without
      • Without Ethernet switch: - each individual unit must be plugged into
        – Lakeshore 330 – used for monitoring temperatures PRIVATE NETWORK
        – LabJack Analog and Digital signal monitoring PUBLIC NETWORK
        – Network power switch PRIVATE NETWORK
    • With Ethernet switch
      – All of the Ethernet devices are first plugged into the Ethernet switch on the shutter and filter wheel base and then a single cable goes to the switch in the prime focus cage.
  – Power – 1 power connection
    • all electronic devices are plugged into the integrated network power switch. Only the main power cable for the network switch actually needs to be plugged in.

• COMPUTER INSTALLATION
  – Connect the optical fibers to the Adnaco card (upper fiber interface) and the Archon interface card
  – Plug in 2 power cables for the computer redundant power supplies
  – Plug in the Ethernet cable to Eth0 (upper network port if vertical, left-most port if the computer is horizontal)
THERMAL MONITORING AND HOLD TIME
WASP First Cool-down

WASP Cool-down January 15-17, 2016

Liquid Nitrogen Hold-Time > 24 hours after optimization
How long does WASP take to cool to operational temperatures?

Liquid Nitrogen Hold-Time > 24 hours after optimization
BASIC OPERATION OF WASP
Basic Operations of WASP

Enter Exposure Time
Press GO button!

Enter Image Basename
Enter Image Number

Select Detector Readout Mode
Science ONLY
Guide ONLY
Focus ONLY
Science, Focus
Science, Guide
Science, Focus, Guide
Guide sequence

Select FITS output format
Single Extension FITS
Multi-Extension FITS

Select Image Display Settings
Trim prescan and overscan
Bin the Display Image

Subtract BIAS
Browse for MASTER BIAS image
Subtract BIAS from Display Image
Subtract BIAS from Disk Image

Display in DS9
Move Target to Bullseye

Electronics Monitoring
Enter Overscan

Guiding
Continuous Button

Observing Controls
Dithering
Astrometry.net
SExtractor
Science Image Display
WASP Scripting

Science Detector
Exposure Progress
Read Progress
Retrieve Progress

Guide / Focus Detector
Exposure Progress
Read Progress
Retrieve Progress

Observation Controls

Acquiring Images: /data2/dani.WASP/20190117/image_image_388.fits

WASP Prime Focus Camera

Science Detector Exposure Time
Guide Detector Exposure Time

PIXEL/Counts
LINE/Counts

STOP

Continuous Button

Move Target to Bullseye
Quick FOCUS

Astrometry.net
Sextractor
Science Image Display

Dithering

Science Image Display

WASP Scripting

Electronics Monitoring

Enter Overscan

GUIDING
Basic Operations of WASP
Electronics Monitoring

- Backplane ID
- Board Identification
- CCD Power
- Logging level
- Frame Buffers
- Poll Controller
- System Log
- Science Image Rotation
Basic Operations of WASP
Timing File

ACF File - Timing and Configuration

3/22/19
Caltech Optical Observatories
45
Basic Operations of WASP

- The first thing an observer needs to decide when using WASP is the format and naming of the FITS image files produced.
  - FITS images are stored within date stamped image directories that are automatically created whenever the software is started. The date stamped image directory is created under the DEFAULT_DATA_DIRECTORY specified in the Archon.ini configuration file. The currently configured output data directory is DEFAULT_DATA_DIRECTORY = /rdata2/data/WASP. This directory may be changed in the future dependent upon disk space requirements.

- FITS format: WASP science detector images are readout using 4 separate amplifier channels and the observer can choose to write the images as either multi-extension FITS images with each quadrant written to a different image extension (including the prescan and overscan) or as single image frames. The default is to use the “raw” format where a single image extension is included in the FITS file. If the primary analysis method will be using iraf’s ccdproc then the multi-extension format is preferred. For all other analysis methods the “raw” format is preferred.

- What overscan does the observer want in the image? The overscan size can be configured by setting the overscan size in the provided spinner control. Observers using ccdproc may want to set a specific overscan size. Observers who do not require the overscan for their data reduction process can simply set it to zero.

- Image naming convention:
  
  DEFAULT_DATA_DIRECTORY + $YYYYMMDD+$BASENAME+$IMAGENUMBER.FITS
  
  where
  
  DEFAULT_DATA_DIRECTORY = default data directory specified in the Archon.ini configuration file
  $YYYYMMDD = the date directory in year, month and day format
  $BASENAME = the image base name entered in the base name text field
  $IMAGENUMBER = the image number, this number automatically increments after each image is taken

  GUIDER IMAGES = DEFAULT_DATA_DIRECTORY + $YYYYMMDD+$BASENAME + ”_guide_”+$IMAGENUMBER.FITS
  FOCUS IMAGES = DEFAULT_DATA_DIRECTORY + $YYYYMMDD+$BASENAME + ”_focus_”+$IMAGENUMBER.FITS
Specifying how the FITS image is displayed and written to disk

- Specifying the image name: Set the BASENAME and the IMAGE NUMBER

| Image Path | /data2/data/WASP20180126 | Base Name | wasp_image | Image Number | 22 |

- Specifying the FITS format: Single or Multi-Extension FITS

- Determine how you want the image displayed: Trim prescan and overscan?
  - The size of the WASP images makes image display slow so the displayed image is binned 2x2 by default.
  - You can turn off binning by setting the “Bin Display Image” spinner control to 1x1 or increase the size of the binning.

- Do you have a bias frame that you’d like to subtract from the displayed image or the disk image?

<table>
<thead>
<tr>
<th>Automated BIAS Subtraction</th>
<th>/MASTER_BIAS_2018_1_1.fits</th>
<th>Apply to Displayed Image</th>
<th>Apply to Disk Image</th>
</tr>
</thead>
<tbody>
<tr>
<td>Status Messages</td>
<td>Dimension of current and bias image are not the same!!</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
WASP Readout Modes

• Detector Readout Modes
  – **Science ONLY** – reads out only the science detector
  – **Guide ONLY** – reads out only the guide detector
  – **Focus ONLY** – reads out only the focus detector
  – **Science, Focus** – reads out both the science and focus detector after EXPTIME. Used for focus monitoring by automatically running Sextractor on each image.
  – **Science, Guide** – first exposes the guide detector for the selected guide exposure time, finds all stars in the image, automatically selects guide stars and configures the ROI for fast readout, guide during exposure, close shutter and readout the science detector.
  – **Guide, Science, Focus** – first exposes the guide detector for the selected guide exposure time, finds all stars in the image, automatically selects guide stars and configures the ROI for fast readout, guide during exposure, close shutter and readout the science detector then the focus detector.
  – **Guide sequence only** – first exposes the guide detector for the selected guide exposure time, finds all stars in the image, automatically selects guide stars and configures the ROI for fast readout, guide during exposure, close shutter. This is essentially a test mode for guiding and is not used in observing.
WASP Sub-array Mode

- Sub-arrays may be readout centered in any of the 4 quadrants.
- Quadrants are numbered starting in the lower left quadrant and then numbered counterclockwise.

<table>
<thead>
<tr>
<th>Subarray Size</th>
<th>Readout Time (seconds)</th>
</tr>
</thead>
<tbody>
<tr>
<td>256</td>
<td>0.961</td>
</tr>
<tr>
<td>512</td>
<td>1.927</td>
</tr>
<tr>
<td>768</td>
<td>2.929</td>
</tr>
<tr>
<td>1024</td>
<td>3.726</td>
</tr>
<tr>
<td>1280</td>
<td>4.883</td>
</tr>
<tr>
<td>1536</td>
<td>5.898</td>
</tr>
<tr>
<td>1792</td>
<td>6.857</td>
</tr>
<tr>
<td>2048</td>
<td>7.801</td>
</tr>
<tr>
<td>2304</td>
<td>8.883</td>
</tr>
<tr>
<td>2560</td>
<td>9.863</td>
</tr>
<tr>
<td>2816</td>
<td>10.874</td>
</tr>
<tr>
<td>3000</td>
<td>11.553</td>
</tr>
</tbody>
</table>
THE IMAGE DISPLAY SYSTEM
Science, Guide and Focus Detectors
Installed in the WASP dewar

E2V 6144x6160 CCD231-C6
Back Illuminated Science Detector

Lower half of the dewar with VIB attached fully assembled
WASP – Palomar P200 Telescope
On-Sky Orientation of Science, Guide and Focus CCDs
September 13, 2016

Science Detector Plate Scale = 0.18 arc-seconds/pixel
Target Acquisition and Placement with WASP

- **Where do you want your target to be placed on the WASP detector?**
- The WASP image display system integrates telescope control into the image display using the “Target to Bulls-eye” system.
- Place the “Target” cursor on the object that you wish to move and the “Bulls-eye” cursor where you want the object to be placed. The calculated offset required to move the target to the bulls-eye location is displayed on the main WASP controls panel.
- Press the “Move Target to Bulls-eye” button and the target is moved to the selected location.

![Diagram of WASP interface with labeled components: Target Cursor, Bulls-eye Cursor, Move Target to Bulls-eye Button, RA and Dec Offsets, Telescope Move Progress Bar, Right Mouse Click opens the cursor selection menu.](image)
WASP Image Display System

- The WASP instrument software uses two separate image displays for the science detector images and the guider/focus detector images.
- Access to the image displays is available from the “Observing Tools” menu on the main WASP controls panel.
WASP Image Display System
Image Contrast Controls

- The science CCD image display has a sophisticated image contrast and brightness control that uses 2 mouse cursors to set the scaling limits for the image.
- First enable auto-scaling then place the “background” cursor on an area of the image to set the base of the image scale and the “guide” cursor on a star that sets the top of the image scale.
WASP MECHANISMS
The WASP camera uses the same shutter and filter-wheel originally created for LFC.

Unlike LFC, the shutter and filter-wheel are controlled via a GUI accessed from the “Observing Tools” menu on the main panel.

It is necessary to “HOME” both mechanisms prior to use.

IMPORTANT: FIRST HOME THE SHUTTER THEN THE FILTER-WHEEL

EVEN MORE IMPORTANT: NEVER MOVE BOTH MECHANISMS AT THE SAME TIME!!! (communication to both mechanisms is through a single serial port)

Shutter homing normal takes less than 60 seconds

Filter wheel homing can take up to 5 minutes so please be patient.

The filter wheel is SLOW due to the need to position the filter with high precision so that flats are reproducible.
WASP Mechanisms
Shutter and Filter Wheel Control

- Palomar staff are responsible for loading the filters into the filter-wheel.
- Once the filters are placed in the filter-wheel the Palomar staff will select the correct filter for each position using the combo-box controls (Filter 1,2,3,4) and then save the configuration so that future software starts contain the correct filter name.

- Changing filters can effect the focus position by as much as 2.8mm so it’s necessary that the software “knows” which filter was used to focus the instrument.

- If the “Adjust FOCUS” checkbox is checked then changing the filter also automatically changes the focus based upon the knowing which filter was used for focusing:
  - Example: r’ and i’ filters focus at the same position but the g’ filter focuses +1.5mm higher. If you focus in i’ or r’ and then change to g’ the software automatically changes focus by 1.5mm.

---

ACTIVATE SHUTTER and ACTIVATE FILTER-WHEEL

Select current filter in position: PALOMAR STAFF ONLY!!
The WASP filter-wheel takes approximately 18.68 +/- 1.1 seconds to move from one filter position to the next.

<table>
<thead>
<tr>
<th>Filter Wheel Move</th>
<th>Time (seconds)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2 to 1</td>
<td>20.02</td>
</tr>
<tr>
<td>1 to 2</td>
<td>18.52</td>
</tr>
<tr>
<td>2 to 3</td>
<td>18.16</td>
</tr>
<tr>
<td>3 to 4</td>
<td>18.76</td>
</tr>
<tr>
<td>2 to 3</td>
<td>18.22</td>
</tr>
<tr>
<td>3 to 4</td>
<td>19.38</td>
</tr>
<tr>
<td>1 to 2</td>
<td>18.05</td>
</tr>
<tr>
<td>2 to 3</td>
<td>18.39</td>
</tr>
<tr>
<td>3 to 4</td>
<td>19.63</td>
</tr>
<tr>
<td>4 to 3</td>
<td>20.61</td>
</tr>
<tr>
<td>3 to 2</td>
<td>16.81</td>
</tr>
<tr>
<td>2 to 1</td>
<td>17.55</td>
</tr>
</tbody>
</table>

Mean                  18.68 seconds/position
Standard Deviation    1.07
FOCUSING THE INSTRUMENT
Focusing the WASP camera

• There are 3 principle mechanisms for focusing the WASP camera
  – (1) Run a “focus script” that acquires a set of images at different focus values and analyze the results using the provided focus graph tool. This should only be necessary when the instrument is first installed on the telescope and the best focus position is truly unknown.
  – (2) Run the “Quick Focus” tool. This is a quick method for determining focus by measuring the donut metric at two positions offset from and estimated best focus and calculating the best focus from the results.
  – (3) Monitor best focus using the integrated focus detector. The focus detector is offset from the science focal plane by 1.485 mm so the best focus can be calculated directly from a measurement of the donut metric on both the science and focus detectors.
Do we really know the value of Alpha?

Estimated best focus should be constant and not effected by initial estimate of focus.
For what value of Alpha is the standard deviation of the estimated best focus a minimum?

Value of Alpha for minimum noise in Estimated Best Focus = 0.68
Estimated error in Best Focus Estimate = 0.053 mm
Do we really know the value of Alpha? (continued)
Does the offset from the initial guess change the ALPHA value?

Estimated best focus should be constant and not effected by initial estimate of focus.
For what value of Alpha is the standard deviation of the estimated best focus a minimum?

OFFSET = 1.0mm Value of Alpha for minimum noise in Estimated Best Focus = 0.63
Estimated error in Best Focus Estimate = 0.11mm

OFFSET = 0.7mm Value of Alpha for minimum noise in Estimated Best Focus = 0.68
Estimated error in Best Focus Estimate = 0.053 mm
Focusing the WASP camera
Running a complete focus curve analysis

Open and run the focus.txt script

Open the Sextractor controls panel and
Press the Focus Graph Tool button in the upper right corner of the control

Press “Select Files” and browse to locate the files produced by the Focus script and select and add them to the tool.

Press the “Process” button and wait while the tool analyzes the images and creates the plots

Read “Best Focus” from the graph minimum

Specify the following parameters:
Initial focus
Focus increment
Exposure Time
Image BASENAME
Starting image number
Focusing the WASP camera
Running the Quick Focus Tool

Equation (1) \[ F_0 = (F^+ + F^-)/2 + (A_4^- - A_4^+)/2\alpha. \]

Quick Focus Tool

- The “Quick Focus” Tool is the fast way to determine the best focus.
- Requirements:
  - Estimate the best focus
  - Set the offset in mm
- Process: The “Quick Focus” Tool first takes an image with the focus set to (ESTIMATED_FOCUS – OFFSET) followed by setting the focus to (ESTIMATED_FOCUS + OFFSET) and taking a second image. Each image is then analyzed using Sextractor to calculate the median donut metric in each image. Using the measured donut metric on both sides of focus and the known value of \( \alpha \), the best focus can be calculated from equation (1).
- How close does the estimated focus need to be? For Equation (1) to be valid each of the images must be taken of different sides of focus. Therefore, the estimate must be within +/- OFFSET in mm from the true best focus.
- How can you tell that you’re really at the “best” focus? If you set focus to the “best” focus estimate and then repeat the measurement (i.e. re-run the tool) the resulting high and low side donut metrics should be the same indicating that the measurements were taken symmetrically about the best focus position.
- ADVANTAGE: The measurement of the donut metric for images that are >= 0.5mm out of focus is not dependent upon the seeing and doesn’t show the same noise.
WASP – Palomar P200 Telescope Focus Analysis
Developing the “Donut” method for focus determination

\[ A_4^- = \alpha(F_0 - F^-) + \delta, \]
\[ A_4^+ = \alpha(F^+ - F_0) + \delta \]

\[ \alpha = 0.803_{\text{arcseconds}} \]
\[ \delta = 0.241_{\text{arcseconds}} \]

Pupil Image Regime
Low Signal to Noise
Poor Sextractor Source Identification

Out of Focus Donuts Regime
High Signal to Noise
Sextractor Compatible Sources

Seeing Dominate Regime
Gaussian Profiles

Optimum Focus Donut Regime
+1.0 to –2.0 mm
from best focus

Best Focus = 26.3mm
Caltech Optical Observatories
Focusing the WASP camera
Turn on FOCUS Monitoring

Equation (1) \[ F_0 = \left( F^+ + F^- \right)/2 + (A^-_4 - A^+_4)/(2\alpha). \]

Focus Monitoring

• The focus monitoring system uses the integrated focus detector which is offset from the science detector by 1.485mm. By taking an image of both the science and focus detector simultaneously and measuring the donut metric on each the requirements of equation (1) can be satisfied.

• Substituting \( F^- = F^+ - 1.485 \text{mm} \) into equation (1) allows a best focus estimate to be calculated from knowledge of the current focus, the measured donut metric on the two detectors and a known \( \alpha \).

• In order for the calculation to fulfill the requirements of equation (1) the science detector must be either at best focus or on the high side of focus. For this reason the focus monitoring tool is better used to monitor and make minor adjustments to focus rather than as the primary means of determining best focus.

• In order for the “Focus Monitoring” function to work both the science and focus detectors must be readout and analyzed. As a result the readout mode must be set to either Science, Focus or Guide, Science, Focus.

Focus Donut Analysis

\[ \begin{array}{c|c}
\text{Focus Donut Analysis} & \text{Donut Metric} \\
\hline
\text{Science Detector} & 0.0 \\
\text{Focus Detector} & 0.0 \\
\text{Focus - Science} & 0.0 \\
\text{Best Focus} & 0.0 \\
\end{array} \]
WASP – Palomar P200 Telescope Focus Analysis
September 13, 2016
Measuring the focus offset of the integrated STA focus detector

The design offset between the focus CCD and the science CCD is 1.45mm

Design Offset  = 1.450 mm
Measured Offset = 1.485 mm
Focusing the WASP camera
The shape of the WASP best focus surface

FWHM Map of the WASP science detector

CONTOUR INTERVAL = 0.05 arcseconds per contour
Focusing the WASP camera
The shape of the WASP best focus surface December 2018

FWHM Map of the WASP science detector

CONTOUR INTERVAL = 0.05 arcseconds per contour

30 second “Best Focus” image used for generating the focus height map

FWHM arcseconds

CONTOURS

0.95
1
1.05
1.1
1.15
1.2
1.25
1.3
1.35
1.4
1.45
1.5
1.55
1.6
1.65
1.7
1.75
1.8
1.85
1.9
1.95
2

DS9 Contour METHOD = BLOCK

1.4 arcsec
1.35 arcsec
1.45 arcsec
1.30 arcsec
SEXTRACTOR INTEGRATION
WASP and Sextractor
GUI integration with DS9

• When Sextractor is run inside WASP it automatically displays the selected image in DS9 (if Display in DS9 is ON).
• After analysis the Sextractor catalog file is read and output as DS9 region file.
• All of the green circles in the image below correspond to entries in the original, unfiltered Sextractor output catalog.
• The red squares in the image correspond to the subset of star that pass the filtering for signal to noise, flux and distance from the nearest adjacent star.
• The goal of the filtering step is to identify, as far as possible, those stars that are not saturated at any point within their aperture, and that are separated sufficiently from adjacent stars.
• Filtering acts to remove outliers in the distribution and to select stars that might be appropriately used as guide stars.
WASP and Sextractor
Overview – Basic Operations

• Sextractor is actually run as a separate command line program but the GUI allows the observer to easily modify extraction parameters and specify the output configuration from the GUI.
• The Sextractor configuration files are created on the fly containing the information in the GUI.
• Not all Sextractor options are available but most are.
• You do NOT need to know Sextractor to run WASP.
• All Sextractor configuration is done internally by the WASP software so observers do not need to edit any parameters for the system to work.
• This control is intimately integrated with DS9 and all identified sources are written into a “regions” file and displayed as an overlay.
• Sextractor catalogs and the associated DS9 region files are stored in the same image directory that contains the FITS image and named after the original image.

3/22/19
Caltech Optical Observatories
WASP and Sextractor

Extraction Parameters

Basic Output Parameters

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>CATALOG_TYPE</td>
<td>ASCII_HEADER</td>
</tr>
<tr>
<td>PARAMETER_NAME</td>
<td>default</td>
</tr>
<tr>
<td>CHECK_IMAGE_TYPE</td>
<td>NONE</td>
</tr>
<tr>
<td>CHECK_IMAGE_NAME</td>
<td>check.fits</td>
</tr>
</tbody>
</table>

Extraction Parameters

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>DETECT_TYPE</td>
<td>CCD</td>
</tr>
<tr>
<td>DETECT_MINAREA</td>
<td>80</td>
</tr>
<tr>
<td>DETECT_MAXAREA</td>
<td>0</td>
</tr>
<tr>
<td>THRESH_TYPE</td>
<td>RELATIVE</td>
</tr>
<tr>
<td>DETECT_THRESH</td>
<td>10.00</td>
</tr>
<tr>
<td>ANALYSIS_THRESH</td>
<td>10.00</td>
</tr>
<tr>
<td>MASK_TYPE</td>
<td>CORRECT</td>
</tr>
</tbody>
</table>

Photometry Parameters

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>MAG_ZERO</td>
<td>0.00</td>
</tr>
<tr>
<td>INTERP_MAG</td>
<td>0.00</td>
</tr>
</tbody>
</table>

Background and Associations

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>BACK-ground</td>
<td>0</td>
</tr>
<tr>
<td>BACK_MAX</td>
<td>0</td>
</tr>
</tbody>
</table>

Weights and Flags

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>WEIGHTS</td>
<td>0</td>
</tr>
</tbody>
</table>

For a help understanding each of these parameters, please refer to the following primary source:
WASP and Sextractor
How does WASP actually use Sextractor?

- WASP uses Sextractor internally in 2 fundamental ways
  1. extraction of source locations for guiding
  2. calculation of the “Donut” metric from Sextractor calculated 2nd moments
  - Source locations are also used as the starting point for complete 2D Gaussian fits to determine the FWHM as an image quality metric.

- In general, WASP doesn’t simply calculate the image quality metric (either FWHM or Donut metric) for a star but instead uses Sextractor to calculate the image quality of ALL extracted sources in an image and displays the distribution of values found across the entire field.

- Experience has shown that the median Donut metric and the median FWHM are much better measure of delivered image quality than the mean or any single measurement in the field.
WASP and Sextractor
2D Gaussian Analysis of stars in a WASP image

• After running Sextractor and identifying the sources, an observer can choose to fit 2D Gaussian to each of the identified sources using the Focus Analysis control.
• The primary output of this analysis is a histogram of the FWHM values measured in the image along with the mean, median and standard deviation of the distribution.

- Calculate Gaussian FWHM of source in the image
- Process FITS image of FWHM Map
- 3D map of the FWHM distribution in the image
- 3D map of the astigmatism in the image
- FHWM Histogram
- FWHM table
- FITS image output name
- Image FWHM Map saved as a FITS image
WASP and Sextractor

Overview

- The WASP instrument software makes extensive use of Sextractor for both focus and guiding.
- Sextractor is integrated into the WASP software through a GUI available in the “Observing Tools” menu.

Main Sextractor GUI Panel

Output Parameters

Filtered Sources

Extracted Sources Table

Focus Graph Analysis

Two of the output configuration Choices are used extensively in WASP
“Coordinates Only” – used to identify source for guiding
“Out of Focus Donut” – used for focus measurement

Additionally useful output configurations:
SCAMP output configuration – needed for SCAMP and for determining distortion maps of the WASP field
WASP and Sextractor
Creating Focus Curves with both the Donut metric and FWHM

• If the user has observed a set of images at different focus values (see Focusing WASP) the simplest and most robust way to analyze the results is to use the “Focus Graph Tool”
• The “Focus Graph Tool” is available from the main Sextractor panel by pressing the “Focus Graph” button in the upper right hand corner of the display.
• Procedure:
  – Browse for FITS image files
  – Press the “Process” button.
• The donut metric graph (left) and the FWHM graph (right) are updated after each image is analyzed.
• After completion the table of values may be exported for further analysis.
**Guide, Science, Focus Operational Mode Timeline**

<table>
<thead>
<tr>
<th>Science Detector Exposure Time</th>
<th>Focus Detector Exposure Time</th>
</tr>
</thead>
<tbody>
<tr>
<td>Shutter Open</td>
<td>Shutter Open</td>
</tr>
<tr>
<td>Guider Exposure Time</td>
<td>Guider Exposure Time</td>
</tr>
<tr>
<td>Complete Guider Readout</td>
<td>Complete Guider Readout</td>
</tr>
<tr>
<td>7.5 seconds</td>
<td>7.5 seconds</td>
</tr>
<tr>
<td>SExtractor Analysis Time</td>
<td>SExtractor Analysis Time</td>
</tr>
<tr>
<td>Guider Exposure Time</td>
<td>Guider Exposure Time</td>
</tr>
<tr>
<td>Guider Exposure Time</td>
<td>Guider Exposure Time</td>
</tr>
<tr>
<td>Guider Exposure Time</td>
<td>Guider Exposure Time</td>
</tr>
<tr>
<td>Guider Exposure Time</td>
<td>Guider Exposure Time</td>
</tr>
<tr>
<td>ROI Readout Time</td>
<td>ROI Readout Time</td>
</tr>
<tr>
<td>ROI Readout Time</td>
<td>ROI Readout Time</td>
</tr>
<tr>
<td>ROI Readout Time</td>
<td>ROI Readout Time</td>
</tr>
<tr>
<td>ROI Readout Time</td>
<td>ROI Readout Time</td>
</tr>
<tr>
<td>Waiting for Science Exposure</td>
<td>Waiting for Science Exposure</td>
</tr>
<tr>
<td>to Complete</td>
<td>to Complete</td>
</tr>
<tr>
<td>Science Detector Readout</td>
<td>Science Detector Readout</td>
</tr>
<tr>
<td>~11.5 seconds</td>
<td>~11.5 seconds</td>
</tr>
<tr>
<td>Focus Detector Readout</td>
<td>Focus Detector Readout</td>
</tr>
<tr>
<td>~15.6 seconds</td>
<td>~15.6 seconds</td>
</tr>
</tbody>
</table>

*Note:* After the SExtractor Analysis the system calculates how many guide frames can be observed before the science exposure is completed.
Guiding and the WASP camera

- The Hale telescope is a remarkably stable platform for observing with cumulative tracking error on the order of 1 arc-second every 15 minutes.
  - Tracking errors are typically larger in RA than in Dec.
  - Tracking errors in Dec increase with increasing distance from zenith but don’t reach the same magnitude as the errors in RA.

- Guiding is typically not needed for exposures less than 300 seconds duration and has practically no effect for exposure times less than 150 seconds.

- Attempting to guide for exposure times less than 100 seconds may result in no actually guide frames being taken since the system calculates how many frames it can fit into the time remaining in the science exposure.

- Minimum possible science exposure with guiding:
  - 2*(GUIDER_EXPOSURE_TIME + GUIDER_READOUT)+SEXTRACTOR_ANALYSIS_TIME
  - Example: GUIDER_EXPOSURE_TIME = 5.0 seconds
    GUIDER_READOUT_TIME = 7.5 seconds
    SEXTRACTOR_ANALYSIS_TIME = 10.0 seconds – note: analysis may be much faster (1.0 second)
    Minimum Science exposure for 1 guide frame = 35 seconds

Guide, Science, Focus Operational Mode Timeline

![Timeline Diagram](image.png)

<table>
<thead>
<tr>
<th>GUIDER Exposure Time</th>
<th>Complete Guiding Exposure Time</th>
<th>SExtractor Exposure Time</th>
<th>GUIDER Readout Time</th>
<th>SExtractor Readout Time</th>
<th>SExtractor Exposure Time</th>
<th>Waiting for Science Exposure to Complete</th>
<th>Science Detector Readout</th>
<th>Focus Detector Readout</th>
</tr>
</thead>
<tbody>
<tr>
<td>7.5 seconds</td>
<td>12.5 seconds</td>
<td>20 seconds</td>
<td>7.5 seconds</td>
<td>15.0 seconds</td>
<td>22.5 seconds</td>
<td>30 seconds</td>
<td>37.5 seconds</td>
<td>45.0 seconds</td>
</tr>
</tbody>
</table>

Note: After the SExtractor Analysis, the system calculates how many guide frames can be observed before the science exposure is completed.
Guiding and the WASP camera
How does guiding actually work?

- WASP has only a single shutter and both the science and guide CCD’s are located on the same focal plane. As a result, guiding with WASP requires that the shutter remain open while the science CCD is exposed and the guide detector must be read out while the CCD is still exposing.

- WASP attempts to completely automate the guiding process by internally finding all of the stars in the guider CCD field and then setting up the guide configuration as follows:
  - Run Sextractor to locate all stars in the image
  - Remove stars that are saturated on any pixel
  - Sort the resulting stars by total flux and select a single star at the 90th percentile (i.e. 90 percent of the stars in the image have less flux than the selected star) (note: the 90th percentile value is adjustable on the GUI)
  - Configure the region of interest (ROI) as a strip ROI_WIDTH wide (default = 64 pixels), centered on the selected star.
  - Identify any other stars that are wholly within the ROI.
  - Setup “guide boxes” on each star in the set identified in the previous step. (this step involve calculating where the stars will fall on the ROI based upon their coordinates in the original full frame guide image.

- With WASP the observer does not select the stars used for guiding; the system automatically picks the appropriate star.

Guide, Science, Focus Operational Mode Timeline

<table>
<thead>
<tr>
<th>Science Detector Exposure Time</th>
<th>Focus Detector Exposure Time</th>
</tr>
</thead>
</table>

<table>
<thead>
<tr>
<th>Shutter Open</th>
<th>Complete Guider Readout 7.5 seconds</th>
<th>Sextractor Analysis Time</th>
<th>Guider Exposure Time</th>
<th>ROI Readout Time</th>
<th>ROI Readout Time</th>
<th>ROI Readout Time</th>
<th>ROI Readout Time</th>
<th>ROI Readout Time</th>
<th>RO Waiting for Science Exposure to Complete</th>
<th>Science Detector Readout ~11.5 seconds</th>
<th>Focus Detector Readout ~15.0 seconds</th>
</tr>
</thead>
</table>

Note: After the Sextractor Analysis the system calculates how many guide frames can be observed before the science exposure is completed
Guiding and the WASP camera
Example timeline for a GUIDE, SCIENCE, FOCUS mode image
Guiding and the WASP camera

What guiding parameters are adjustable by the observer?

- So what guiding parameters are adjustable and how do they effect the guide performance?
  - Guide Exposure Time (Default = 2 seconds)
  - Guide Box Size (Default = 24 pixels)
  - ROI Height (Default = 64)
  - Guide Star selection percentile (Default = 90%)
  - PID loop gain

- **Guide Exposure Time** guidelines: guide exposure times between 1 and 10 seconds are appropriate. The selected guider exposure time depends upon how many and how bright the star in the guider CCD image are.

- The **ROI height** (i.e. the width of the ROI strip) effects only HOW MANY stars will be measured to calculate the guide signal. Increasing the ROI height increases the size of the ROI strip and more stars will be wholly contained within this strip. The example on the right shows that 3 guide stars are contained within the configured ROI strip.

- **Guide star selection percentile**. The slider control allows the observer to adjust the percentile used for selecting the primary guide star. If only one bright star is in the field along with a large number of faint stars you can force it’s selection by setting the slider to 100%.

- **Guide Box Size**. The guide box size can be adjusted from 16 to 100 pixels with the default value at 24. Typical seeing at Palomar is on the order of 1 arc-second (FWHM = ~5 pixel) so most stars require a minimum guide box size of 16x16. Increasing the guide box size also increases the chance that other stars will contaminate the measurement and decreases the number of stars that fit wholly within the configured region of interest.

- **Gain**. The guiding loop is a simple proportional controller (only the P of the PID formalism is used) and the gain on the loop can be directly adjusted from the GUI.
Guiding and the WASP camera
Guiding in action

Adjustable ROI Height

PRIMARY GUIDE STAR: X,Y coordinates
ROI start and end line
Number of stars in ROI

Adjustable: Percentile for Guide Star selection

Adjustable: Gain

Full Frame GUIDER Image in DS9

Individual ROI strip image with guide boxes

GUIDING

Cross-section Graph

Guide Graph: clear

Each point on the guide graph represents the analysis of a different ROI image

PRIMARY GUIDE STAR
Guide Box centered on selected star

Note: Primary guide star box is RED and centered in the ROI band

Guide Box placed on an additional Star that falls wholly within the ROI

Caltech Optical Observatories

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Guiding and the WASP camera

The Guider Control Panel

- The Guider Control Panel is integrated into the guider image display system and supports the operation of the guiding system. The Guider Control Panel is accessed from the guider image display panel under the “Tools” menu.
- The Guider Control Panel maintains the list of guide star locations and the record of calculated guide corrections.
Guiding and the WASP camera

What do you need to monitor during guiding?

- WASP Main Controls Panel
- Guiding Panel
- DS9 Full Guider Image Display
- Guider ROI display
- Guide Correction Chart
- Guider Control Panel
- Guider Image Cut Levels
The results of Auto-Guiding
NGC 598 R’ filter
Image Quality Assessment

- Comparison between FWHM distribution with and without guiding.
- Two 300 second exposure images in the same (r’) filter taken consecutively with and without guiding

300 Second – Auto-guiding image

300 Second – no guiding image
WASP SCRIPTING LANGUAGE
WASP supports a simple scripting language that executes sequential commands stored in simple text files. All commands consist of keywords followed by parameters (if necessary). If you find that additional commands would be desirable please request them.

### WASP SCRIPTING LANGUAGE

<table>
<thead>
<tr>
<th>Keywords</th>
<th>Parameters</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>EXPTIME</td>
<td>double</td>
<td>sets the exposure time for the science detector and focus detector if both are being readout</td>
</tr>
<tr>
<td>BASENAME</td>
<td>string</td>
<td>sets the basename for the FITS image file</td>
</tr>
<tr>
<td>IMAGENUMBER</td>
<td>int</td>
<td>set the image number for the FITS image file</td>
</tr>
<tr>
<td>GEXPTIME</td>
<td>double</td>
<td>set the guider exposure time</td>
</tr>
<tr>
<td>MODE</td>
<td>string</td>
<td>sets the operational mode of the camera (i.e. the detectors that will be readout)</td>
</tr>
<tr>
<td>SCIENCE_ONLY</td>
<td></td>
<td></td>
</tr>
<tr>
<td>FOCUS_ONLY</td>
<td></td>
<td></td>
</tr>
<tr>
<td>GUIDE_ONLY</td>
<td></td>
<td></td>
</tr>
<tr>
<td>SCIENCE_FOCUS</td>
<td></td>
<td></td>
</tr>
<tr>
<td>SCIENCE_GUIDE</td>
<td></td>
<td></td>
</tr>
<tr>
<td>SCIENCE_GUIDE_FOCUS</td>
<td></td>
<td></td>
</tr>
<tr>
<td>EXPOSE</td>
<td></td>
<td>starts the exposure of the camera given the current camera settings.</td>
</tr>
<tr>
<td>FOCUSGO</td>
<td>double</td>
<td>sets the telescope focus to the value specified in the command</td>
</tr>
<tr>
<td>FOCUSINC</td>
<td>double</td>
<td>increments the focus from the current value to the current value + offset</td>
</tr>
<tr>
<td>MOVE_TELESCOPE</td>
<td>double,double</td>
<td>move the telescope by the specified offset in RA and Dec</td>
</tr>
<tr>
<td>SET_DITHER_PATTERN</td>
<td></td>
<td>name of a currently available dither pattern</td>
</tr>
<tr>
<td>SET_DITHER_SCALE</td>
<td>double</td>
<td>sets the scale factor for the dither pattern (scales pattern to the sky)</td>
</tr>
<tr>
<td>RETRIEVE_DITHER_IMAGE</td>
<td></td>
<td>retrieves a DSS image of the current telescope field</td>
</tr>
<tr>
<td>FILTER</td>
<td>string</td>
<td>selects the current filter, returns error if the specified filter is not installed.</td>
</tr>
</tbody>
</table>
WASP Scripting
A simple example: FLATS in 4 filters

- One of the most useful simple scripts automatically takes a set of N images (N=5 in the example below) in each of the 4 filters installed in WASP. Note that the script sets the focus for each filter using the FOCUSINC command.

```plaintext
BASENAME flat_i_prime_
IMAGENUMBER 1
FILTER i'
EXPTIME 40.0
EXPOSE
EXPOSE
EXPOSE
EXPOSE
EXPOSE

BASENAME flat_g_prime_
IMAGENUMBER 1
FOCUSINC 1.5
FILTER g'
EXPTIME 60.0
EXPOSE
EXPOSE
EXPOSE
EXPOSE
EXPOSE

BASENAME flat_u_prime_
IMAGENUMBER 1
FOCUSINC 0.1
FILTER u'
EXPTIME 60.0
EXPOSE
EXPOSE
EXPOSE
EXPOSE
EXPOSE

BASENAME flat_r_prime_
IMAGENUMBER 1
FILTER r'
EXPTIME 40.0
EXPOSE
EXPOSE
EXPOSE
EXPOSE
EXPOSE
```

Select which detector to readout
Set the BASENAME of the images
Reset the image number
Change the filter
Set the exposure time
Execute an exposure
WASP Scripting
A more complex example: DITHERS in 3 filters

- The following script carries out a set of three, 5-point dither patterns in three filters (r’, i’, g’) of the object M101 with a 120 second exposure time at each position. A total of 15 fits images are produced by this script.

```
Retrieve a DSS image of the dither field
Set the BASENAME of the image
Reset the image number
Change the filter
Set the exposure time
Select the dither pattern
Set the dither scale factor
Execute dither pattern
```

```
RETRIEVE_DITHER_IMAGE
  BASENAME M101_DITHER_R_
  IMAGENUMBER 1
  FILTER r'
  EXPTIME 120.0
  SET_DITHER_PATTERN DITHER_5_SIMPLE
  SET_DITHER_SCALE 100.0
  EXECUTE_DITHER

BASENAME M101_DITHER_I_
  IMAGENUMBER 1
  FILTER i'
  EXPTIME 120.0
  SET_DITHER_PATTERN DITHER_5_SIMPLE
  SET_DITHER_SCALE 100.0
  EXECUTE_DITHER

BASENAME M101_DITHER_G_
  IMAGENUMBER 1
  FILTER g'
  EXPTIME 120.0
  SET_DITHER_PATTERN DITHER_5_SIMPLE
  SET_DITHER_SCALE 100.0
  EXECUTE_DITHER
```

Example output after data reduction
WASP Scripting Language

WASP Scripting Control

Select script file
Current Selected Command
Press GO button

Selected Command Number

Press PAUSE: Pauses execution after current command

Press STOP: Stops execution after current command

Start from the beginning of the script
Start from the selected command number

Script Execution Log

Script editor

Press Parse Script File after editing
DITHER OPERATIONS
WASP Dither Pattern Control

Introduction

- **Executing a Dither sequence**
  - (1) Update Current Telescope Position (this tells the control the current telescope pointing)
  - (2) Download DSS reference image (based on the second Palomar Sky Survey)
  - (3) Optional (open the DSS image display window)
  - (4) Select the dither pattern to be executed.
  - (5) Set the scale factor for the dither pattern’s layout on the sky.
    - Typically dither patterns are specified with each position having an absolute x, y offset from the center between 0 and 1. The layout of the pattern on the sky is then determined by the scaling factor. The X and Y coordinates are multiplied by the scale factor to determine the offset in arcseconds from the pattern’s center point. The RA and Dec coordinates of each dither position is calculated and displayed in the dither positions table.
  - (6) Press the GO button
    - Note: exposures are taken using whatever the current configuration (i.e. exposure time, overscan, image name, etc.) of the GUI is in effect.
WASP Dither Pattern Control

The Dither Control in operation

While the Dither pattern is running you can either PAUSE or STOP the pattern at any point. Note that the current Observation step must finish before the control is reset to ready (i.e. if you stop during an exposure that exposure must finish first).

During dither acquisition the dither position overlay changes Color based upon the state of the observation:
GREEN = COMPLETED
YELLOW = NOT COMPLETED
RED = CURRENTLY OBSERVING

Progress Bar indicates the percentage of the total pattern completed

DITHER PATTERN TABLE:
GREEN = dither position completed
RED = dither position currently being observed
GREY = dither position not yet observed

If you Z the telescope offsets prior to starting the dither, then FACSUM and the telescope status displays will display the real current offset from the dither center.
WASP Dither Pattern Control

A tour of the Dither Pattern Control

Retrieve a DSS image of the dither field

Optional: Enter Object Name

Optional: Resolve coordinates for the object using NED or SIMBAD

RA and Dec coordinates for the center of the dither pattern

Offset from current position to the selected dither position.

Offset from dither center to the selected dither position.

Selecting a row in table is linked to “Selected Dither Coordinates” and the Move to Dither Position Button

Selecting a row in table is linked to “Selected Dither Coordinates” and the Move to Dither Position Button

Execution State:
- GREEN completed
- RED observing
- GREY not yet observed

Dither Sequence Number

RA and Dec of dither position

X,Y offset to position

Dither Positions Table:

PRESS GO!! when ready

Open a previously downloaded image

Display DSS image with Dither overlay

Display dither position graph

Select the dither pattern

Retrieve a DSS image of the dither field

Optional: Enter Object Name

Optional: Resolve coordinates for the object using NED or SIMBAD

RA and Dec coordinates for the center of the dither pattern

Offset from current position to the selected dither position.

Offset from dither center to the selected dither position.

Selecting a row in table is linked to “Selected Dither Coordinates” and the Move to Dither Position Button

Execution State:
- GREEN completed
- RED observing
- GREY not yet observed

Dither Sequence Number

RA and Dec of dither position

X,Y offset to position

Dither Positions Table:
The image download control panel allows observers to load a target list (i.e., in the same format as used by FACSUM, either *.csv or *.ptic format) and then automatically download DSS images for each of the fields in the list.

The primary use for this panel is to allow observers to download the DSS images in the afternoon for the coming nights run making operations slightly faster.

Select row in the table and then press "Retrieve Image" to load the image into the control.

EXAMPLE CSV FORMAT:  
Ring Nebula,18:53:35.079,+33:01:45.03,2000  

NAME,RA,DEC,EQUINOX
WASP and Astrometry.net

- The WASP computer contains a local distribution of the Astrometry.net program and its associated set of database files.
- The main WASP GUI’s “Observing Tools” menu allow the observer access to the built in Astrometry.net GUI

- Browse for FITS image
- Identified SOURCES in the Image
- All Sources found in the image
- Batch process for running multiple files at once
WASP and Astrometry.net

- Astrometry.net is an excellent way to refine the WCS coordinates in WASP images.
- WASP has a large enough field of view that very few images fail to solve with Astrometry.net.
- Supplying the plate scale (0.18 arc-seconds/pixel ± 0.01) and tolerance with a small search radius speeds up the solution substantially and most analyses complete in around 60 seconds.

Which image do you want to display after the solution is found?
- objs.png = png file annotated with sources
- ngc.png = png file with no annotation
- indx.png = displays “QUAD” used for solution
- .new = FITS with updated WCS

RA and Dec retrieved from FITS header

Input estimated Plate Scale: WASP 0.18 arc-seconds/pixel
Plate Scale Tolerance: 
Search Radius about RA and Dec
WASP OPTICAL DISTORTIONS
Optical Quality Assessment
Gaussian FWHM Map and examples of coma at the periphery of the optical field

Coma NE quadrant
Coma SE quadrant
Coma NW quadrant
Coma SW quadrant

FWHM Map
FWHM Image
Astigmatism Map
Optical Quality Assessment
Example: SCAMP evaluation of astrometric distortions

The image of NGC 598 depicted below is a composite of 5 dither positions observed in 3 separate filters (r', i', g')
APERTURE PHOTOMETRY
Aperture Photometry

Aperture Photometry Tool Integration

First you need to “Activate” the Aperture Photometry Mode so that images are read into the correct structures for doing the aperture calculations. You need to “Activate” prior to taking the image.

Note: The code used for the aperture photometry calculations was written by Russ Laher of IPAC and incorporated into the WASP instrument. If there is a problem anywhere in the calculations it is solely my responsibility not Russ’s.

Each time either the mouse is clicked on the image or a new image is taken the Aperture photometry parameters a updated in the GUI.

After an image has been taken you can right-mouse click on the image to display the cursor dialog and select “Aperture Photometry Mode”.

Clicking on the image will then place a “Photometry” cursor on the image using a circular aperture with a Aperture Major Radius and a “Sky Inner Radius” and “Sky Outer Radius” controlled by the dialog spinners.
Aperture Photometry
Monitoring the photometry of multiple objects

If the + sign is engaged (i.e. icon turns green) each click on the image will add a new photometry cursor to the list of objects to monitor. Positions in this table are considered “static” photometry records.

Each time the image is clicked with the mouse a new record is added to the “Cursor Photometry Record” (note as long as the + button is not active)

Each new image will produce a new set of measurements in the “static photometry records” table for each photometry cursor.

Photometry Graph: Each “static” photometry cursor appears as a separate “trace” in the photometry graph.
Aperture Photometry
Monitoring the photometry of multiple objects in multiple filters

Static Photometry cursors (4 in this case) are plotted separately for each filter to facilitate monitoring multi-filter observations.

Science Image Display
Observations in each filter are plotted on a separate graph.

Photometry Graph: Each "static" photometry cursor appears as a separate "trace" in the photometry graph.
Aperture Photometry
Bias structure of a WASP image

HISTOGRAM OF A BIAS IMAGE

BIAS image of the WASP Science Detector

BIAS RANGE = 250 adu
Aperture Photometry

Bias structure of a WASP image

Histogram of a Bias Image After Offset Correction

Original Bias Range = 250 adu

Bias Measurements in Each Quadrant Before Offset Correction

<table>
<thead>
<tr>
<th>Quadrant</th>
<th>Median</th>
<th>Mean</th>
<th>Standard Deviation</th>
<th>Offset</th>
<th>Tapline</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>607</td>
<td>606.8</td>
<td>1</td>
<td>193</td>
<td>Tapline 3</td>
</tr>
<tr>
<td>2</td>
<td>794</td>
<td>793.6</td>
<td>1.1</td>
<td>6</td>
<td>Tapline 2</td>
</tr>
<tr>
<td>3</td>
<td>530</td>
<td>529.7</td>
<td>1.4</td>
<td>270</td>
<td>Tapline 0</td>
</tr>
<tr>
<td>4</td>
<td>738</td>
<td>737.6</td>
<td>1.1</td>
<td>62</td>
<td>Tapline 1</td>
</tr>
</tbody>
</table>
Aperture Photometry
Comparison between FLAT field images in different filters

\[ \text{r'}\ \text{filter} \quad \text{i'}\ \text{filter} \quad \text{g'}\ \text{filter} \quad \text{z'}\ \text{filter} \quad \text{u'}\ \text{filter} \]

\[ \text{R-BESSEL}\ \text{filter} \quad \text{V-BESSEL}\ \text{filter} \quad \text{B-BESSEL}\ \text{filter} \quad \text{H-ALPHA}\ \text{filter} \]

with 50 overscan
PHOTOMETRIC ANALYSIS – ZERO POINT MAGNITUDES
### Photometric Standards

**August 2017 – WAS**


#### PG1323-086

<table>
<thead>
<tr>
<th>V</th>
<th>B</th>
<th>U</th>
<th>i</th>
<th>B-V</th>
<th>U-B</th>
<th>V-I</th>
<th>V-I</th>
</tr>
</thead>
<tbody>
<tr>
<td>PG1323-086</td>
<td>13.48</td>
<td>13.34</td>
<td>12.64</td>
<td>13.52</td>
<td>13.68</td>
<td>-0.14</td>
<td>-0.68</td>
</tr>
<tr>
<td>PG1323-086A</td>
<td>13.59</td>
<td>13.98</td>
<td>13.97</td>
<td>13.33</td>
<td>13.08</td>
<td>0.399</td>
<td>-0.019</td>
</tr>
<tr>
<td>PG1323-086B</td>
<td>13.40</td>
<td>14.16</td>
<td>14.43</td>
<td>12.58</td>
<td>12.57</td>
<td>0.761</td>
<td>0.265</td>
</tr>
<tr>
<td>PG1323-086C</td>
<td>14.00</td>
<td>14.71</td>
<td>14.95</td>
<td>13.68</td>
<td>13.26</td>
<td>0.707</td>
<td>0.245</td>
</tr>
</tbody>
</table>

#### PG1525-071

<table>
<thead>
<tr>
<th>V</th>
<th>B</th>
<th>U</th>
<th>i</th>
<th>B-V</th>
<th>U-B</th>
<th>V-I</th>
<th>V-I</th>
</tr>
</thead>
<tbody>
<tr>
<td>PG1525-071</td>
<td>15.04</td>
<td>14.85</td>
<td>13.68</td>
<td>15.14</td>
<td>15.94</td>
<td>-0.211</td>
<td>-1.177</td>
</tr>
<tr>
<td>PG1525-071A</td>
<td>13.50</td>
<td>14.27</td>
<td>14.56</td>
<td>13.06</td>
<td>13.08</td>
<td>0.773</td>
<td>0.282</td>
</tr>
<tr>
<td>PG1525-071B</td>
<td>16.32</td>
<td>17.12</td>
<td>17.26</td>
<td>15.84</td>
<td>16.05</td>
<td>0.729</td>
<td>0.341</td>
</tr>
<tr>
<td>PG1525-071C</td>
<td>13.82</td>
<td>14.24</td>
<td>14.31</td>
<td>13.26</td>
<td>13.01</td>
<td>1.116</td>
<td>1.074</td>
</tr>
<tr>
<td>PG1525-071D</td>
<td>16.3</td>
<td>16.69</td>
<td>16.91</td>
<td>15.89</td>
<td>15.95</td>
<td>0.393</td>
<td>0.224</td>
</tr>
</tbody>
</table>

#### PG1633+099

<table>
<thead>
<tr>
<th>V</th>
<th>B</th>
<th>U</th>
<th>i</th>
<th>B-V</th>
<th>U-B</th>
<th>V-I</th>
<th>V-I</th>
</tr>
</thead>
<tbody>
<tr>
<td>PG1633+099</td>
<td>14.38</td>
<td>14.20</td>
<td>13.21</td>
<td>14.45</td>
<td>14.67</td>
<td>-0.191</td>
<td>-0.595</td>
</tr>
<tr>
<td>PG1633+099A</td>
<td>13.29</td>
<td>16.13</td>
<td>16.00</td>
<td>14.81</td>
<td>14.84</td>
<td>0.872</td>
<td>0.305</td>
</tr>
<tr>
<td>PG1633+099B</td>
<td>13.68</td>
<td>14.04</td>
<td>15.06</td>
<td>13.27</td>
<td>13.68</td>
<td>1.081</td>
<td>1.037</td>
</tr>
<tr>
<td>PG1633+099C</td>
<td>13.24</td>
<td>13.08</td>
<td>15.14</td>
<td>12.12</td>
<td>12.09</td>
<td>1.144</td>
<td>1.146</td>
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<tr>
<td>PG1633+099D</td>
<td>13.69</td>
<td>14.26</td>
<td>14.28</td>
<td>13.86</td>
<td>13.84</td>
<td>0.535</td>
<td>0.021</td>
</tr>
<tr>
<td>PG1633+099E</td>
<td>13.13</td>
<td>13.94</td>
<td>14.29</td>
<td>12.39</td>
<td>12.16</td>
<td>0.841</td>
<td>0.337</td>
</tr>
<tr>
<td>PG1633+099F</td>
<td>13.76</td>
<td>14.27</td>
<td>14.18</td>
<td>13.24</td>
<td>12.73</td>
<td>0.878</td>
<td>0.254</td>
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</tbody>
</table>

#### SA 107 599

<table>
<thead>
<tr>
<th>V</th>
<th>B</th>
<th>U</th>
<th>i</th>
<th>B-V</th>
<th>U-B</th>
<th>V-I</th>
<th>V-I</th>
</tr>
</thead>
<tbody>
<tr>
<td>SA 107 599</td>
<td>14.875</td>
<td>15.373</td>
<td>15.616</td>
<td>14.242</td>
<td>13.866</td>
<td>0.698</td>
<td>0.243</td>
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<tr>
<td>SA 107 600</td>
<td>14.883</td>
<td>15.387</td>
<td>15.436</td>
<td>14.545</td>
<td>14.184</td>
<td>0.503</td>
<td>0.049</td>
</tr>
<tr>
<td>SA 107 601</td>
<td>14.659</td>
<td>16.098</td>
<td>17.323</td>
<td>13.723</td>
<td>12.865</td>
<td>1.022</td>
<td>1.265</td>
</tr>
<tr>
<td>SA 107 602</td>
<td>15.516</td>
<td>15.207</td>
<td>13.639</td>
<td>11.573</td>
<td>11.043</td>
<td>0.931</td>
<td>0.585</td>
</tr>
</tbody>
</table>

#### Diagrams

![Diagram of PG1633+099](image1.png)

![Diagram of SA 107 599](image2.png)

![Diagram of PG1525-071](image3.png)

![Diagram of PG1323-086](image4.png)
Patroclus-Menoetius Asteroids
April 9, 2018 WASP IMAGES
Magnitude vs. Magnitude Uncertainty
WASP Instrument April 9, 2018

ZERO POINT MAGNITUDES SUMMARY:

G = 27.266   1 SECOND EXPOSURE
R = 26.569   1 SECOND EXPOSURE
I = 26.132   1 SECOND EXPOSURE
Z = 24.699   1 SECOND EXPOSURE
PANSTARRS Apparent Magnitudes vs. Instrumental Magnitudes
Calculation of Zero Point Magnitude for Sloan Filters
April 9, 2018

PANSTARRS APPARENT MAGNITUDES

G Magnitude (electrons/second)
\[ y = 0.9914x - 27.266 \]
\[ R^2 = 0.99871 \]

R Magnitude (electrons/second)
\[ y = 0.9454x - 26.569 \]
\[ R^2 = 0.99458 \]

I Magnitude (electrons/second)
\[ y = 0.9556x - 26.132 \]
\[ R^2 = 0.997 \]

Z Magnitude (electrons/second)
\[ y = 0.923x - 24.659 \]
\[ R^2 = 0.99214 \]

ZERO POINT MAGNITUDES SUMMARY:

G = 27.266 1 SECOND EXPOSURE
R = 26.569 1 SECOND EXPOSURE
I = 26.132 1 SECOND EXPOSURE
Z = 24.659 1 SECOND EXPOSURE
SUMMARY of Sensitivities
Calculation of Zero Point Magnitude for Sloan Filters
April 9, 2018

<table>
<thead>
<tr>
<th>Detector</th>
<th>WASP</th>
<th>LFC</th>
<th>PHARO</th>
</tr>
</thead>
<tbody>
<tr>
<td>Quantum Efficiency</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>WASP</td>
<td>0.174</td>
<td>5.9</td>
<td></td>
</tr>
<tr>
<td>LFC</td>
<td>17.8</td>
<td>0.180</td>
<td>2</td>
</tr>
<tr>
<td>PHARO</td>
<td>13</td>
<td>0.250</td>
<td>5.3</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Zero Point (1e/sec)</th>
<th>WASP</th>
<th>LFC</th>
<th>PHARO</th>
</tr>
</thead>
<tbody>
<tr>
<td>WASP</td>
<td>25.409</td>
<td>27.266</td>
<td>26.569</td>
</tr>
<tr>
<td>LFC</td>
<td>24.900</td>
<td>27.300</td>
<td>27.400</td>
</tr>
<tr>
<td>PHARO</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Measured Sky Background (e/sec/arcsec²)</th>
<th>WASP</th>
<th>LFC</th>
<th>PHARO</th>
</tr>
</thead>
<tbody>
<tr>
<td>WASP</td>
<td>339.2</td>
<td>733.4</td>
<td>826.8</td>
</tr>
<tr>
<td>LFC</td>
<td>247.0</td>
<td>741.0</td>
<td>1173.0</td>
</tr>
</tbody>
</table>

PANSTARRS APPARENT MAGNITUDES

ZERO POINT MAGNITUDES SUMMARY:
G = 37.266 1 SECOND EXPOSURE
R = 36.189 1 SECOND EXPOSURE
I = 36.182 1 SECOND EXPOSURE
Z = 24.659 1 SECOND EXPOSURE
R Band Zero-Point Magnitude
Normalized for 1 Second Exposure Time

Aperture Photometry Tool - Determination of Zero Point Magnitude

**R Band Filter**

<table>
<thead>
<tr>
<th></th>
<th>Normalized by Exposure Time</th>
<th>Not Normalized</th>
<th>Airmass</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Zero Point</td>
<td>Error</td>
<td>Zero Point</td>
</tr>
<tr>
<td>PG1323-086</td>
<td>25.185</td>
<td>0.022</td>
<td>28.878</td>
</tr>
<tr>
<td>PG1525-071</td>
<td>25.305</td>
<td>0.016</td>
<td>28.997</td>
</tr>
<tr>
<td>SA 107 599-602</td>
<td>25.422</td>
<td>0.052</td>
<td>27.922</td>
</tr>
<tr>
<td>PG1633+099</td>
<td>25.425</td>
<td>0.023</td>
<td>28.678</td>
</tr>
<tr>
<td>PG1633+099</td>
<td>25.521</td>
<td>0.024</td>
<td>28.021</td>
</tr>
<tr>
<td>Mean</td>
<td>25.372</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Stdev</td>
<td>0.1294</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Extinction Coefficient: **-0.2007**

Zero Point at Airmass 1.00: **25.695**

![Graph showing linear and logarithmic fits with R² values]
I Band Zero-Point Magnitude
Normalized for 1 Second Exposure Time

Aperture Photometry Tool - Determination of Zero Point Magnitude

<table>
<thead>
<tr>
<th>I Band Filter</th>
<th>Normalized by Exposure Time</th>
<th>Not Normalized</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Zero Point</td>
<td>Error</td>
</tr>
<tr>
<td>PG1323-086</td>
<td>25.797</td>
<td>0.0439</td>
</tr>
<tr>
<td>PG1525-071</td>
<td>25.183</td>
<td>0.0467</td>
</tr>
<tr>
<td>SA 107 599-602</td>
<td>24.829</td>
<td>0.0464</td>
</tr>
<tr>
<td>PG1633+099</td>
<td>24.919</td>
<td>0.0526</td>
</tr>
<tr>
<td>Mean</td>
<td>25.182</td>
<td></td>
</tr>
<tr>
<td>Stdev</td>
<td>0.4368</td>
<td></td>
</tr>
</tbody>
</table>

Extinction Coefficient 0.67
Zero Point at Airmass 1.00 24.703
WHAT CAN GO WRONG?
What can go wrong?

• NEVER start 2 instances of the software at the same time.
  – Attempts to connect to the Archon controller when it is already connected to another process causes the controller to fault and requires power cycling to correct.

• Known Bug: If you guide while executing a dither pattern the guiding works correctly for the first and last image of the pattern but appears to not work for the intermediate frames.

• Remember to “Activate Shutter” and “Activate Filter-wheel” after homing the mechanisms. If you forget the shutter will not open when an exposure is taken and the filter-wheel will not move during script execution. (the default will be changed when the next version of the software is deployed.)
APPENDIX A: ELECTRONICS STATE MACHINE AND TIMING
Flush all arrays

Idling Flush 1 row

No parameter

Read Full Frame
ReadArray

Flush Guide and wait for Trigger

Trigger "trigger_GuideRead"

Read ROI many times

Flashing Guide and wait for Trigger

Trigger "trigger_GuideRead"

Param_GStartSubWindow Param_GHeightSubWindow param_GEndLines

Read Focus with Frame Transfer Param_SubExposeTime Param_BurstNb Param_SciencePixels

Exposure time = Trigger "trigger_FocusRead" - Trigger "trigger_ScienceExpose"

Exposure time = Trigger "trigger_ScienceRead" - Trigger "trigger_ScienceExpose"

Exposure time = Trigger "trigger_GuideRead" - Trigger "trigger_ScienceExpose"

Read bursts of rows with integrating time between them.

Read bursts of rows with integrating time between them.

Param_ScienceLines Param_SciencePixels

Param_ScienceLines

Param_ScienceClassicReadOut

Param_ScienceMovieReadOut

reading modes?

Integrating and wait for Trigger

Trigger "trigger_ScienceRead"

Integration and wait for Trigger

Trigger "trigger_FocusRead"

Reading Guide

Focus

Guide

Science Read

Focus Read

Param_GStartSubWindow Param_GHeightSubWindow param_GEndLines param_GSubExpos param_GuideNbFrames

No parameter
### List of external parameters

#### Triggers:

<table>
<thead>
<tr>
<th>Name of Trigger</th>
<th>Comment</th>
</tr>
</thead>
<tbody>
<tr>
<td>trigger_ScienceExpose</td>
<td>Trigger to start an exposure. No clocking is then sent to the sensor.</td>
</tr>
<tr>
<td>trigger_ScienceRead</td>
<td>Trigger to start a read of the Science detector</td>
</tr>
<tr>
<td>trigger_GuideRead</td>
<td>Trigger to start a read of the Guider detector</td>
</tr>
<tr>
<td>Trigger_FocusRead</td>
<td>Trigger to start a read of the Focus detector</td>
</tr>
<tr>
<td>Trigger_Abort</td>
<td>Trigger to stop current “waiting for trigger” state and goes back in idling mode.</td>
</tr>
</tbody>
</table>

#### Science detector parameters

<table>
<thead>
<tr>
<th>Name of parameter</th>
<th>Comment</th>
</tr>
</thead>
<tbody>
<tr>
<td>param_ScienceLines</td>
<td>Total number of lines per Tap.</td>
</tr>
<tr>
<td>param_SciencePixels</td>
<td>Total number of pixels per Tap</td>
</tr>
<tr>
<td>param_ScienceClassicReadOut</td>
<td>1 if Science Classic full frame ReadOut</td>
</tr>
<tr>
<td>param_ScienceMovieReadOut</td>
<td>1 if Movie ReadOut</td>
</tr>
<tr>
<td>param_ScienceSubLines</td>
<td>Number of lines in each burst</td>
</tr>
<tr>
<td>param_ScienceBurstNb</td>
<td>Number of Bursts. Has to be reset after each frame reading.</td>
</tr>
<tr>
<td>param_ScienceSubExposureTime</td>
<td>Exposure time between each burst</td>
</tr>
</tbody>
</table>

#### “Movie Mode” parameters

<table>
<thead>
<tr>
<th>Name of parameter</th>
<th>Comment</th>
</tr>
</thead>
<tbody>
<tr>
<td>param_GHeightSubWindow</td>
<td>Height of the selected sub-window</td>
</tr>
<tr>
<td>param_GStartSubWindow</td>
<td>First row of the sub-window</td>
</tr>
<tr>
<td>param_GEndLines</td>
<td>Remaining Lines to read to flush the array. = 1032 - param_GStartSubWindow - param_GHeightSubWindow</td>
</tr>
<tr>
<td>param_GuideNbFrames</td>
<td>Number of frames to be read</td>
</tr>
<tr>
<td>param_GSubExpose</td>
<td>Exposure time between frames</td>
</tr>
</tbody>
</table>

#### Guide detector parameters

<table>
<thead>
<tr>
<th>Name of parameter</th>
<th>Comment</th>
</tr>
</thead>
<tbody>
<tr>
<td>param_GSubExposure</td>
<td>Exposure time between frames</td>
</tr>
</tbody>
</table>

#### Focus detector parameters

<table>
<thead>
<tr>
<th>Name of parameter</th>
<th>Comment</th>
</tr>
</thead>
<tbody>
<tr>
<td>param_FocusRead</td>
<td>Read the focus detector right after a read of Science detector</td>
</tr>
</tbody>
</table>
Parameters of the CDS digital processing unit must be updated before the start of a frame reading.

**PIXELCOUNT** to the total number of column per tap  
**LINECOUNT** to the total number of lines per tap

<table>
<thead>
<tr>
<th>Focus Chip</th>
<th>Guide Chip</th>
<th>Science Chip</th>
</tr>
</thead>
<tbody>
<tr>
<td>TAPLINE0=AD3L, 1,0</td>
<td>TAPLINE0=AD1L, 1,0</td>
<td>TAPLINE0=AD5L, 1,0</td>
</tr>
<tr>
<td>TAPLINE1=AD4L, 1,0</td>
<td>TAPLINE1=AD2L, 1,0</td>
<td>TAPLINE1=AD6L, 1,0</td>
</tr>
<tr>
<td>TAPLINE2=</td>
<td>TAPLINE2=</td>
<td>TAPLINE2=AD7L, 1,0</td>
</tr>
<tr>
<td>TAPLINE3=</td>
<td>TAPLINE3=</td>
<td>TAPLINE3=AD8L, 1,0</td>
</tr>
<tr>
<td>SHP1=330</td>
<td>SHP1=330</td>
<td>SHP1=33</td>
</tr>
<tr>
<td>SHP2=340</td>
<td>SHP2=340</td>
<td>SHP2=43</td>
</tr>
<tr>
<td>SHD1=700</td>
<td>SHD1=700</td>
<td>SHD1=76</td>
</tr>
<tr>
<td>SHD2=710</td>
<td>SHD2=710</td>
<td>SHD2=86</td>
</tr>
</tbody>
</table>

Then APPLY using **02APPLYCDS**
Requested Modifications

• REQUESTED MODIFICATIONS TO THE WASP GUI

• DONE Add an OBJECT keyword, and OBSERVER keywords with dialogs on the main panel
• DONE Add a number of repeats for the script
• DONE If possible add a number for exposures (i.e. set up so you can do N exposures)
• DONE add a PAUSE command in the Script Execution System
• DONE Check where and how the photometry records are saved to disk. May need to add an export command
• DONE Can you make separate tables and graphs for different filters for photometry?
• DONE The Sextractor control doesn’t hide the control when closed but closes the program.
• DONE Create a new script location, set the location in the config file
• Make it impossible to move the shutter when the filter wheel is moving.
• Make it impossible to move the filter wheel when the shutter is moving
• Make it possible to display frames that are written to disk as multi-extension fits.
WASP Temperature Control Problem

Confirmation that the heater banana plugs were connected incorrectly.

December 13, 2018

LN2 Tank response to Low Heater Power

Switched banana plug

Heater turned ON

Detector reaches set point (165K)

Heater power decreases after set point reached

Experiment: Turn on heater in the original configuration and look at the LN2 tank temperature. Does the temperature of the LN2 tank change? (YES) Does the cold-plate temperature change? (NO) Switch the banana plugs and repeat the experiment. Does the cold-plate temperature change (YES) Does the LN2 tank temperature change? (NO)