

Astrophotography Primer

Imaging Equipment, Control Software, and Image Processing

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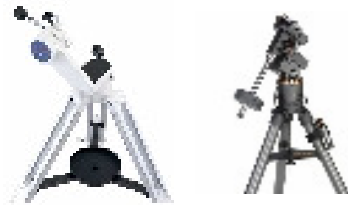


Night Sky Photography by Jeff Lunglhofer

Amateur astronomers and astrophotographers are faced with a dizzying array of equipment choices

Telescope Mounts

- ▶ Available in a range of styles across dozens of manufacturers
 - Fork Mount
 - German Equatorial
 - Dobson



Telescope Designs

- ▶ There is an ever increasing number of choices in optical designs, which is best for you??
 - Catadioptric
 - Refractors
 - Reflectors



Cameras

- ▶ Restricted to film for decades, an array of CCD and DSLR cameras are the best choices for astrophotography today
 - Dedicated CCD
 - DSLRs
 - Modified DSLRs



Software

- ▶ Most astrophotography set-ups are partially or completely driven by a wide range of software packages
 - Planetarium
 - Camera Control
 - Plate Solving
 - Automation



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Difficult choices are required to determine what to buy and when...

Key Questions to Consider

- ▶ Is astrophotography the primary goal for your system?
 - Do you want a dual purpose visual and photographic system?
 - Which is most important to you?
 - How much are you willing to compromise?
- ▶ Have you maxed out the capabilities of your current equipment?
- ▶ Do you like to tinker with astronomy equipment? Are you willing to tear apart equipment and work to improve the performance?
- ▶ What is your budget?
 - This often turns out to be much higher than we ultimately anticipate ☺
- ▶ Does your set-up need to be portable?
- ▶ What kind of telescope/mount/camera/software are you currently comfortable with?
- ▶ What the heck do some of these terms mean?
- ▶ Will your spouse and/or significant other have you bumped off for spending so much time and money on astronomy gear??

...the purpose of this presentation is to help address some of these choices and questions (except that last one)



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Overview

- ▶ Equipment Overview
 - **Mounts**
 - Optics
 - Cameras
- ▶ Software/Hardware
- ▶ Image Processing Basics



Telescope mounts suitable for astrophotography come in two basic forms, with German Equatorial Mounts the clear favorite of imagers

German Equatorial Mount (GEM)

- ▶ Dual axis design that moves in both Right Ascension and Declination
- ▶ Tracking is enabled by attaching a motor drive to the RA axis
- ▶ The RA axis must be fairly accurately aligned with polar north to obtain good tracking

GEM Disadvantages

- ▶ Can not track much beyond the meridian without a “pier flip”
- ▶ Can be more expensive than fork mounts as they are often more massive
- ▶ More confusing set up and non-intuitive telescopes pointing and movement

GEM Advantages

- ▶ More weight can equal more stability for high quality systems
- ▶ Easier to change out instruments, simple dovetail design
- ▶ No need for field de-rotator or wedge
- ▶ Variety of manufacturers of high quality GEMs specifically designed for astrophotography

Fork Mounts

- ▶ Dual axis design that moves in Altitude and Azimuth
- ▶ Tracking is enabled by driving the alt/az drives in level mode
- ▶ A “wedge” can be used to tilt the entire mount into alignment with polar north allowing tracking in azimuth only

Fork Disadvantages

- ▶ Lighter weight and in many cases less stable
- ▶ Since optical tube and fork mount aren't easily separated, total weight can be higher, making one person set-up more difficult with large scopes
- ▶ Less flexible, usually it isn't simple to swap optical tubes
- ▶ ***Not generally produced with astrophotography in mind***

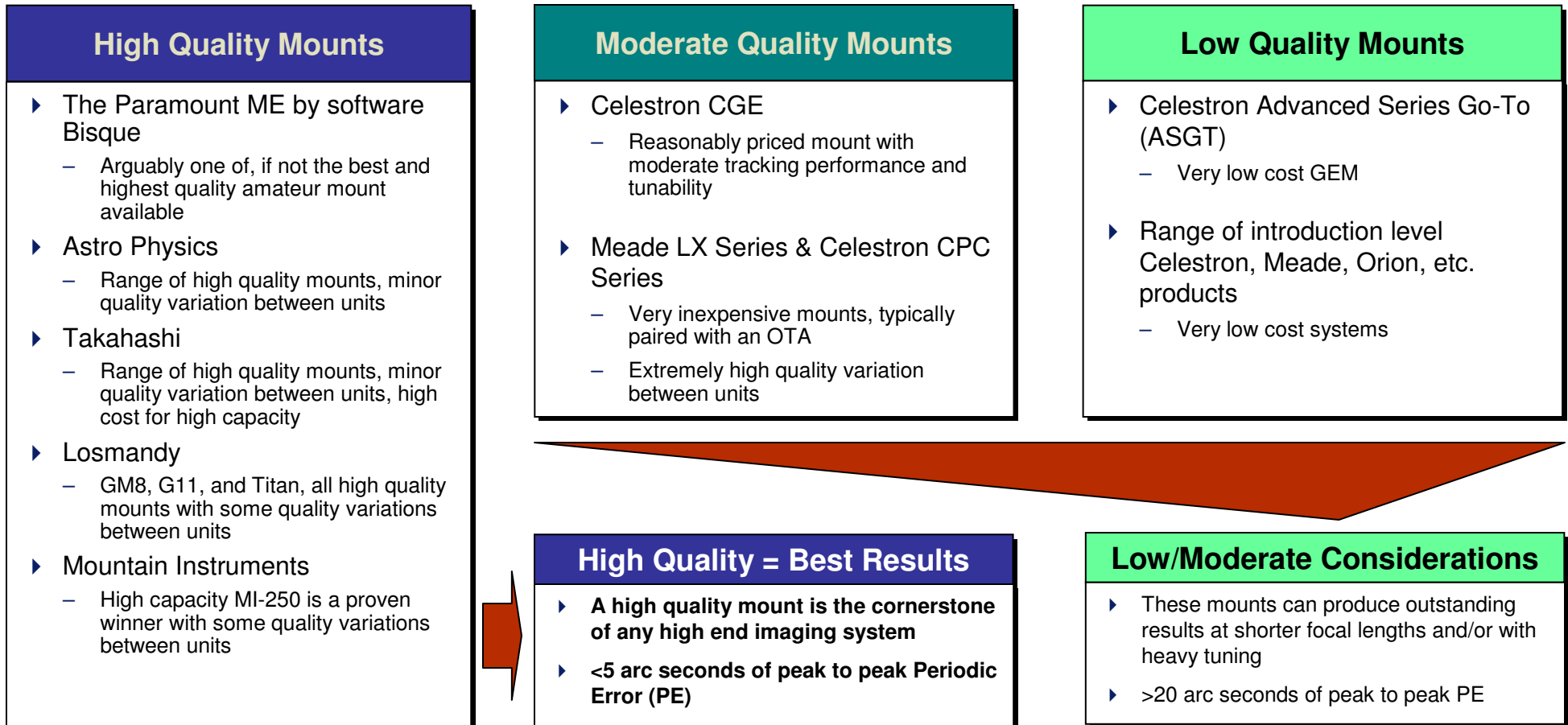
Fork Advantages

- ▶ Very intuitive telescope pointing and movement
- ▶ Less expensive than similar GEM
- ▶ Easier set-up, particularly in level mode (no wedge)
- ▶ More versatile for visual usage (better eyepiece positioning in most cases)



Here is a quick rundown of several selected mount manufacturers and models and my *opinion* of each

Note that I have only considered Go-To capable mounts given their high popularity:



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The following tips can help guide you in your mount selection

- ▶ The mount is the single most important factor in an astrophotography rig and is often gets the least “press coverage”
 - Superb optics and a high end camera system will always produce poor/mediocre results on a poor/mediocre mount.
- ▶ The wildly popular Meade and Celestron SCT/Fork Mount combinations are extremely inconsistent in terms of quality with some having great results and others having significant problems
 - Many LX200 owners report tracking errors in the arc minute range (1 arc minute = 60 arc seconds)
- ▶ If budget restricts you to lower end equipment stick to a short focal length telescope (less than 1000mm) that is more tolerant of tracking errors
- ▶ Those seeking longer focal lengths should seriously consider a higher end mount
 - **Beginners should start by imaging at less than 1000mm!!!!**
- ▶ Starting by identifying your mount allows to you properly pair up the optics and then your camera to achieve the best possible results



The following terminology is frequently used during discussions of telescope mounts

- ▶ **German Equatorial Mount (GEM)** – A specially designed telescope mount that is excellent for astrophotography. GEMs move in right ascension and declination
- ▶ **Fork Mount** – A telescope mount shaped like a two prong fork with an OTA attached to the two fork arms. These simple mounts move in altitude and azimuth, which is effectively just up, down, left, and right.
- ▶ **Periodic Error (PE)** – Often used as a benchmark for the quality of a mount, this term refers to the non-perfect movement of the mount introduced by mechanical flaws in the mount's gearing.
 - **Peak to Peak PE:** Refers to the total amount of error in both the + and – direction from the perfect tracking baseline. For example a mount with 10 seconds of peak to peak PE could have +5 -5 arc seconds of PE, or +4 -6, etc.
 - Unless otherwise specified, PE ratings or estimates for a mount refer to the max expected deviation from the perfect tracing baseline, i.e. “5 arc second PE” would refer to +5 -5 arc seconds of PE, or 10 arc seconds of peak to peak PE.
- ▶ **Periodic Error Correction (PEC)** – A software function that can correct for repeatable PE by compensating the drives using a programmed PE map, sometimes called a curve.
- ▶ **Smooth PE** – A term used to define a PE curve for a mount that is very smooth, exhibiting no high frequency errors that are difficult to fix with either an autoguider or PEC.



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There are a dizzying array of telescope varieties available all of which have strengths and weaknesses, there is no “perfect” design

	Schmidt-Cassegrain	Dall Kirkham	Maksutov-Cassegrain	Schmidt Newtonian
Overview	<ul style="list-style-type: none"> ▶ One of the most popular amateur telescopes available ▶ Compact optical tube consisting of a corrector plate, primary and secondary mirror ▶ Typically F10 or greater and at longer focal lengths 	<ul style="list-style-type: none"> ▶ Very slow optical systems with very long focal length ▶ Very well suited for extremely high magnification viewing ▶ Not many makes and models available, a fairly specialized telescope 	<ul style="list-style-type: none"> ▶ Very popular in smaller apertures (Meade ETX Series) ▶ Compact optical tube consisting of a corrector plate, primary and secondary mirror ▶ Typically F12 or greater and at very long focal lengths 	<ul style="list-style-type: none"> ▶ Mainly produced by Meade with several models available ▶ Fast optics = shorter focal length for a given aperture ▶ Consists of a corrector plate, primary and secondary mirror
Strengths	<ul style="list-style-type: none"> ▶ Compact size is easy to transport and assemble ▶ Well suited to high magnification ▶ Relatively inexpensive relative to aperture ▶ Meade's "ACF" series integrates coma correction into the design ▶ Widely available imaging accessories and add-ons 	<ul style="list-style-type: none"> ▶ Coma is significantly reduced by the extremely long focal length – Coma while present manifests less at longer focal lengths ▶ One of the best lunar/planetary scopes available ▶ Smaller secondary boosts image contrast 	<ul style="list-style-type: none"> ▶ Compact size is easy to transport and assemble ▶ Well suited to high magnification ▶ Widely available from a variety of manufacturers ▶ Smaller secondary boosts image contrast ▶ Coma is reduced by long focal length and heavily curved corrector plate 	<ul style="list-style-type: none"> ▶ Short focal length and relatively large aperture yields fast focal ratio (f4 to f5) ▶ Shorter focal length is excellent for wide field imagers and beginners ▶ Very inexpensive for a given aperture ▶ Corrector plate significantly reduces coma
Weaknesses	<ul style="list-style-type: none"> ▶ Unless corrected, systems suffers from extreme coma and poor off axis performance ▶ Can be very heavy for the provided aperture ▶ Few manufacturers of truly superb optics 	<ul style="list-style-type: none"> ▶ Not very versatile, restricted mainly to long focal length imaging, greater than 1500mm ▶ Smaller secondary size reduces size of image circle, sometimes to less than 35mm ▶ Relatively high cost as there are few available models 	<ul style="list-style-type: none"> ▶ Not very versatile, restricted mainly to long focal length imaging greater than 1500mm ▶ Can be very heavy for the provided aperture due to thickness of corrector plate ▶ Popular models suffer from significant quality inconsistency 	<ul style="list-style-type: none"> ▶ Still suffers from some coma ▶ Limited number of manufacturers and those available from Meade are not high quality instruments ▶ Commonly required information, such as image circle size unavailable

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There are a dizzying array of telescope varieties available all of which have strengths and weaknesses, there is no “perfect” design (cont.)

	Newtonian	Ritchey Chrétien	Apochromat Refractor	Achromat Refractor
Overview	<ul style="list-style-type: none"> One of the most popular amateur telescopes available Simple optical design consisting of a primary and secondary mirror Wide range of focal lengths available across an equally wide range of manufacturers 	<ul style="list-style-type: none"> Designed primary for astrophotography Uses two hyperbolic mirrors (primary and secondary) Extremely popular with some of the best astrophotographers Typically operate at speeds of F8 or greater at focal lengths above 2000mm 	<ul style="list-style-type: none"> Many designs created specifically with astrophotography in mind Extremely popular with some of the best astrophotographers Available in a wide range of focal lengths and speeds 	<ul style="list-style-type: none"> Huge range of manufacturers and options Available in virtually every possible configuration
Strengths	<ul style="list-style-type: none"> Wide variety of focal lengths and speeds available, very versatile telescopes Very reasonable cost relative to aperture Widely available imaging accessories and add-ons 	<ul style="list-style-type: none"> Not significantly affected by coma, but does have some astigmatism The widest and flattest field of any reflecting telescope No cheap models are available due to cost associated with mirrors 	<ul style="list-style-type: none"> No noticeable chromatic aberration Very flat field in a well designed system Huge image circles possible in well designed systems Highest contrast due to lack of any secondary obstruction 	<ul style="list-style-type: none"> Relatively inexpensive compared to apo systems Range of focal lengths make this style very flexible Ideal for use as guide scopes
Weaknesses	<ul style="list-style-type: none"> Unless corrected, faster systems suffer from extreme coma and poor off axis performance Very large optical tube can be cumbersome to transport and handle Most available Newtonian telescopes are very poor quality 	<ul style="list-style-type: none"> This is the most expensive type of reflecting telescope due to the difficulty in manufacturing the mirrors Large secondary obstruction makes this unsuited for planetary observing Relatively heavy and large in size 	<ul style="list-style-type: none"> Highest cost for aperture of any telescope design Primarily suited for wider field imaging with longer focal lengths restricted to very slow or very high priced larger aperture systems “Apo” systems with doublet lens sets are not true apochromats except a few at long focal lengths 	<ul style="list-style-type: none"> Chromatic aberration makes these scopes very difficult for use in astrophotography Lenses and designs are often poor quality There is a flood of extremely low quality refractors on the market today

There are a dizzying array of telescope varieties available all of which have strengths and weaknesses, there is no “perfect” design (cont.)

Specialty Astrographs

Overview

- ▶ Can be any one of the designs listed here, but optimized specifically for astrophotography
- ▶ Often has integrated field flatteners
- ▶ Typically at the highest end of cost for a particular design

Strengths

- ▶ Usually very well designed and product literature will have all the necessary specifications
- ▶ Superb optics in most cases
- ▶ Available from a range of specialty manufacturers in almost every design
- ▶ Hybrid designs harness the best aspects of multiple scope types

Weaknesses

- ▶ Typically the most expensive manufacturer of a particular design
- ▶ Can be long wait times from premium manufacturers

Superb Quality Astrograph Manufacturers

- ▶ **Astro Physics** – Arguably the best apochromatic refracting telescopes available anywhere in the world
- ▶ **Takahashi** – Produces a range of extremely high quality astrographs, from a specialized Ritchey Chrétien model, to refractors and newtonian astrographs.
- ▶ **RC Optical Systems** – Produces some of the best Ritchey Chrétien astrographs available to the amateur community.
- ▶ **ASA** – A premium manufacturer of newtonian astrographs
- ▶ **Dream Telescopes** – Another premium manufacturer of newtonian astrographs



The following tips can help guide you in your optics selection

- ▶ The optical system you choose must match the carrying capacity of your mount, the camera you anticipate using, and your anticipated targets
 - Use the Field of View (FoV) feature in the “The Sky” to experiment with different configurations
- ▶ Approximately 2 arc seconds per pixel is a nice pairing for the bulk of deep sky astrophotography
 - More is okay, but keep in mind that seeing conditions better than 1.5 arc seconds are quite unusual, even for TDS, but it does happen occasionally!!
 - Going below 1 arc second/pixel isn't usually valuable, unless you have a space telescope!
- ▶ The optical and mechanical quality are the two critical considerations with any telescope
 - The focusers on most stock telescopes are not adequate for imaging and suffer from a lack of precision, image shift, and can tilt the imaging chip from the field of focus. Consider the beefiest and best focuser you can afford.
- ▶ Beginners should consider a fast focal ratio (f8 or faster) and a short focal length (<1000mm)
 - A high quality doublet refractor is an excellent first imaging scope, i.e. the Orion 80ED
 - A fast Newtonian telescope paired with a coma corrector can also be a good beginner scope
- ▶ If you already have a SCT get a high quality wedge, carefully collimate your optics, and consider using a focal reduces/flattener...and be ready to struggle anyway...



The following terminology is frequently used during discussions of telescope mounts

- ▶ **Apochromat** – A refracting telescope that refracts all useful wavelengths of light the same way and in the same spot. True apochromats leverage a three lens design in the main lens cell sometimes called a “**triplet**”.
- ▶ **Achromat** – A refracting telescope that uses two elements in the main lens cell, sometimes called a “**doublet**”. It is not possible for a doublet lens design to be truly apochromatic and these refractors will all suffer from color fringing to some extent. Those incorporating ED glass will suffer far less than those with normal optical glass.
- ▶ **Extra-low Dispersion (ED)** – A specialized glass types that significantly reduces the dispersion of light at various wavelengths. High quality refractors will use ED glass and it can be used in a doublet design to produce near apochromatic performance
- ▶ **Image Circle** – The size of the image projected by an optical system at critical focus. This must be large enough to cover the anticipate image chip to prevent vignetting of the image
 - **Fully Illuminated Image Circle** – Some image circles are not fully illuminated and will be brighter in the center vs. the outer edges
- ▶ **Spot Diagram** – A computer generated representation of coma and astigmatism that can affect image quality on the outer fringes of an image circle
- ▶ **Coma** – An optical aberration resulting from light striking the imaging chip at an angle and with a slightly different critical focus point that the center portion of an image circle resulting in a “comet tail” affect.
- ▶ **Astigmatism** – An optical aberration, similar to Coma, which is present in many telescope designs including Ritchey Chretiens, but to a very small extent.
- ▶ **Rack & Pinion Focuser** – A common type of focuser found mostly on lower quality telescopes (with some notable exceptions). Lower quality units make astrophotography very difficult
- ▶ **Crayford Focuser** – A focuser that relies on rollers vs. simple gears to move, typically these are of reasonably high quality

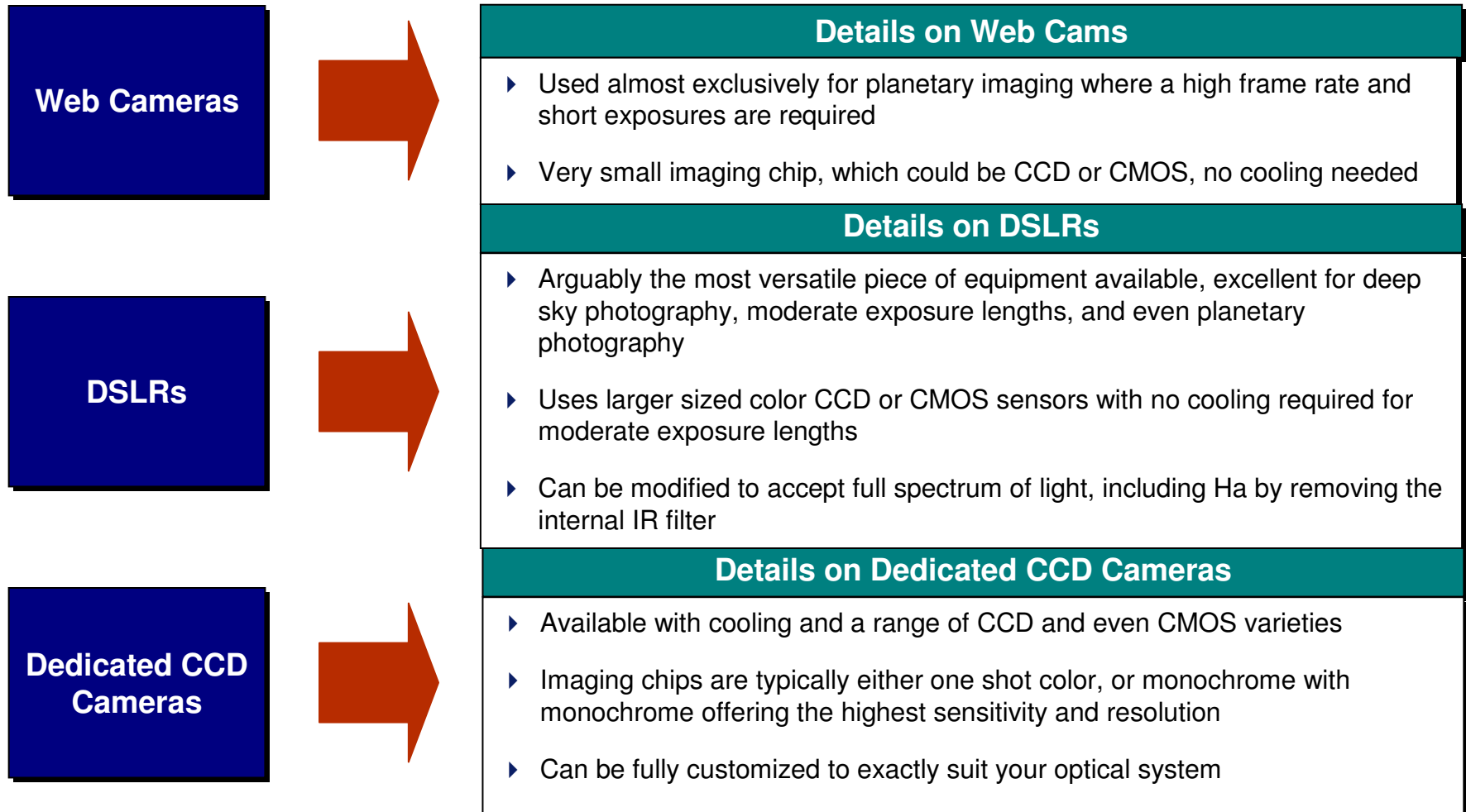


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Three general categories of digital cameras exist that have varying applications in astrophotography



Here are some major considerations in choosing your camera and perfectly matching your optical system

One Shot Color or Monochrome?

- ▶ A bayer matrix is a pattern of green, green, red, and blue filters printed in blocks of four onto the chip's pixels
 - The resulting data for each pixel is combined with it's neighbors to produce a color value
- ▶ One shot color chips are effectively binned 2x2 which means lower effective resolution
- ▶ Narrow band imaging with a one shot color chip is possible but at reduced resolution
- ▶ Creating color images with a monochrome camera requires filters, more exposures, and a lot more processing

Anti-Blooming Gate or Not?

- ▶ Individual pixels have limited capacity to hold a charge, and will spill over to it's neighbors (on the same column) when overfilled, for example by a bright star
- ▶ An ABG covers about 30% of each pixel with a gate to bleed out a certain amount of excess charge
- ▶ ABG cameras are less sensitive than NABG cameras due to the 30% obstruction of each pixel
- ▶ NABG chips are excellent for longer focal length, slower systems, with smaller fields of view where overly bright stars are less of an issue
- ▶ ABG systems are the choice for many non-scientific purposes, i.e. taking pretty pictures with your telescope ☺

Desired Pixel Scale?

- ▶ Do you expect to do a lot of high resolution imaging with excellent seeing?
 - Shoot for 1 to 1.5 arc seconds per pixel
- ▶ Do you expect to do a lot of wide field imaging?
 - Check the Field of View (FoV) in "The Sky" or using Ron Wodaski's free tool CCDCalc
 - Get the largest chip you can afford!
- ▶ Generally shooting for 2 arc seconds per pixel is a good choice for most targets and situations

Quantum Efficiency and Cooling?

- ▶ Higher QE can mean better signal to noise, assuming the peak QE falls in a useful area of the spectrum
 - Emission nebula hunters love a peak QE in the H α range, while galaxy hunters prefer a peak QE in the blue range
- ▶ Do you live in a hot climate where major cooling will be required?
 - -15 to -20C are good general targets
 - Check the power to cool below ambient of your candidate cameras and choose accordingly



The following terminology is frequently used during discussions of cameras for astrophotography

- ▶ **Anti Blooming Gate (ABG)** – A small gate that runs the length of each column, obscuring about 30% of the pixel areas that can bleed away excess charge from any pixel in the column. This can prevent blooming of pixels due to saturation
- ▶ **Non-Anti Blooming Gate (NABG)** – Chips without ABG
- ▶ **CMOS** – An imaging chip that converts charged pixels (charged by interactions with photons) into a digital signal on chip via embedded amplifiers, noise correction, and digital conversion capabilities. These chips output pure digital signals
- ▶ **CCD** – An imaging chip that measures charged pixels via a limited number of output nodes and sent off chip as an analog signal. Much less circuitry and complexity as compared to an equivalent CMOS chip
- ▶ **TEC** – A cooling technology that uses electrical current to rapidly cool one side of a plate by pumping heat to the back side of the plate, which increases significantly in temperature.
- ▶ **Bayer Matrix** – A pattern of Red/Green/Blue filters that is usually printed or overlaid on top of an imaging chip to enable one shot color digital photography
- ▶ **Well Depth** – The total number of electrons an individual pixel can hold before it becomes saturated.
- ▶ **Quantum Efficiency (QE)** – The percentage of photons that strike a pixel that trigger the release of an electron, higher QE equates to higher sensitivity at the specified wavelength.
- ▶ **Binning** – Combining adjacent pixels into one “super pixel”, increasing apparent sensitivity and well depth at the expense of resolution



Overview

- ▶ Equipment Overview
- ▶ **Software/Hardware**
- ▶ Image Processing Basics



Astrophotography is a computer intensive activity requiring a significant amount of software and hardware

Image Acquisition & Camera Control

- ▶ MaximDL – A full featured camera control and image processing suite that can control everything from DSLRs to compatible CCD cameras
- ▶ CCDSoft – A full featured camera control and image processing suite that can control a range of compatible CCD cameras
 - Lacks some features as compared to MaximDL, but has a better scripting interface (great for scientific applications)
- ▶ DSLR Focus – A popular DSLR control and image acquisition package, may no longer be supported by the software author
- ▶ Proprietary Packages – Camera manufacturers (Meade, etc.) often release proprietary software to control their cameras

Image Processing

- ▶ CCDSoft & MaximDL have excellent calibration and processing functions
- ▶ Adobe Photoshop – Probably the ultimate image processing package with a wide range of functions, options, and plugins
- ▶ Registar – Simply the best image alignment software available
- ▶ Sigma – Simply the best image stacking software available
- ▶ CCD Inspector – An excellent tool for analyzing your images for quality, and checking the collimation of your optics
- ▶ Noise Ninja – An excellent plug-in for Photoshop that can reduce the noise in digital photographs
- ▶ CCD Stack – An excellent stacking and processing software package with a wide range of options and settings

Planetarium and Mount Control

- ▶ The Sky – Clearly the leading planetarium software with full mount control in the more advanced levels, also highly scriptable and thus easily interfaces with other software packages
- ▶ Starry Night – An alternative planetarium package with many features, but is not supported by automation software

Automation Packages

- ▶ CCD Commander – A very flexible tool for automating all aspects of astrophotography, very manual setup required
- ▶ CCD Auto Pilot – A menu driven automation package that can control all aspects of an astrophotography session
- ▶ ACP Observatory Control Software – A very advanced automation package with optional web control and other advanced features.

Additional Control Software/Hardware

- ▶ Pole Align Max (PAM) – Freeware polar Alignment utility
- ▶ FocusMax – Freeware autofocus software, requires robotic focuser software/hardware, e.g. Robofocus, TCC, etc.
- ▶ PinPoint – An excellent software package to perform plate solves on acquired image determining their precise location and rotation angle in the sky



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I would suggest the following progression in terms of imaging software and specialized software

Introductory Setup

- ▶ Acquire your images with the software provided by the camera manufacturer
 - CCDSoft for SBIG cameras
 - Canon Remote Capture
 - Meade Autostar Suite
- ▶ Manually focus your telescope using a visual reference star
- ▶ Use a separate guide scope to manually guide or use a web cam as an autoguider with any of the freeware packages available

Intermediate Setup

- ▶ Acquire images using specialized software:
 - CCDSoft, MaximDL, DSLR Focus
- ▶ Use the focusing tools within those software packages to assist you in achieving the best possible focus
- ▶ Autoguide your set-up with a dedicated autoguider camera
 - STV, StarShoot, SBIG internal guider
- ▶ Control the mount from your PC for automatic pointing

Advanced Setup

- ▶ Acquire Images using specialized software
- ▶ Automatically focus via a robotic focuser and autofocus software
- ▶ Use an Off Axis Guider (OAG) to autoguide in front of filters (if necessary)
- ▶ Rotate the camera via a motorized rotator unit
- ▶ Use PinPoint or The Sky's Image Link for highly accurate pointing
- ▶ Automate all imaging and slew activities via one of the available automation packages
- ▶ Images dithered between individual exposures to assist in the elimination of hot/cold pixels during processing



Overview

- ▶ Equipment Overview
- ▶ Software/Hardware
- ▶ Image Processing Basics
 - **Calibration**
 - Selection
 - Alignment
 - Stacking
 - Levels/Curves
 - Layer Blending
 - Assembling an RGB Image



The proper calibration of subs is essential to producing a high quality final image

Dark Subtraction

- ▶ Images taken in total darkness to map the hot pixels in your camera system
- ▶ It is useful to take several dark frames at a variety of exposure lengths and temperatures
- ▶ Taking 8-10 dark frames for each settings allows you to combine them creating a clean final dark free from any cosmic ray hits or other defects
- ▶ Build a library of dark frames for your system
- ▶ Dark frames can be good for several months, even a year or more in some cases

Flat Framing

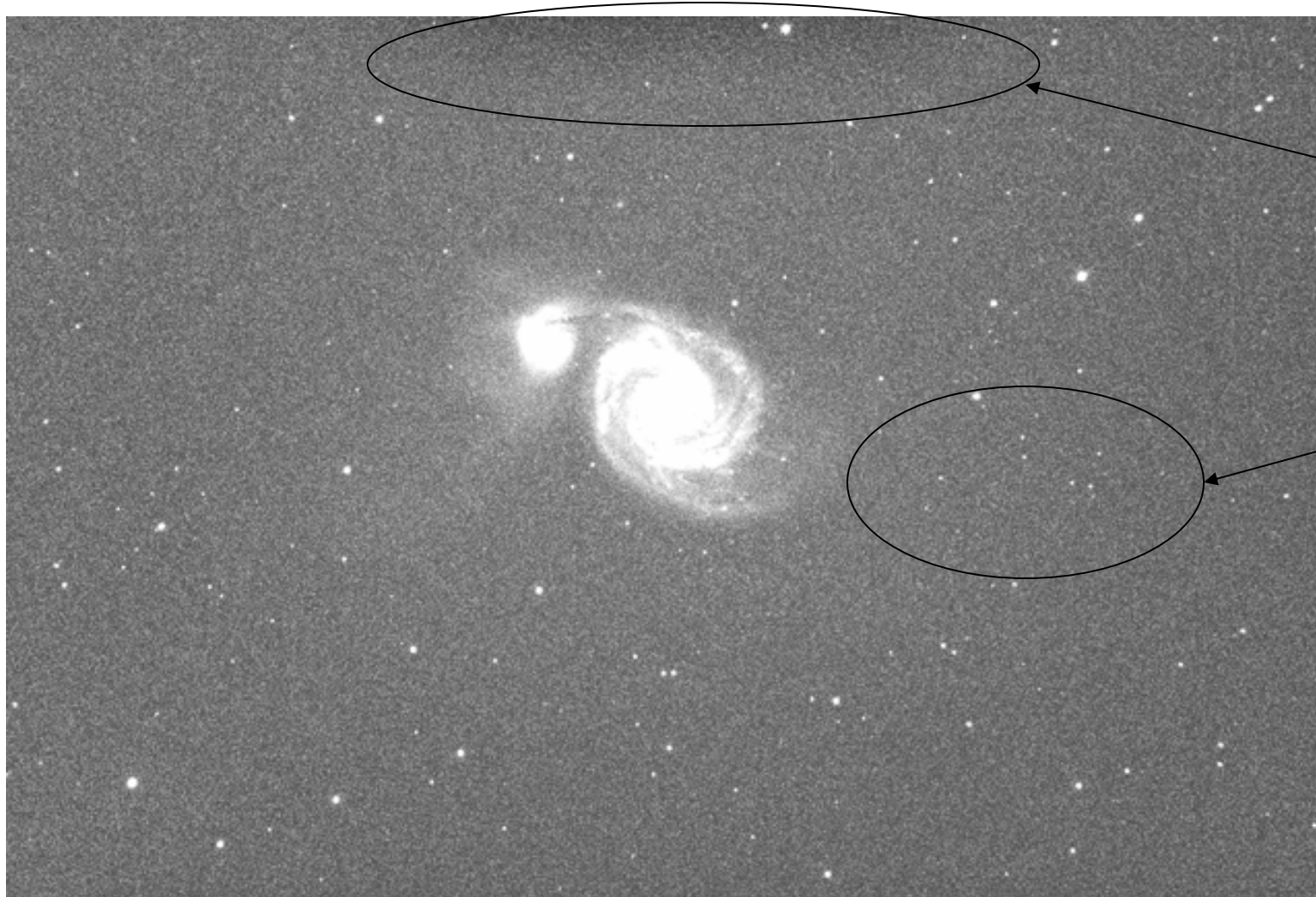
- ▶ A flat field is a map of the optical flaws and shadows cast by your entire imaging system
- ▶ Flats can be taken either at dawn, dusk, or any time using a dimly illuminated surface or a specially designed flat box
- ▶ A flat field should consume approximately 50% of the well depth (on average) of your cameras pixels
- ▶ Always take at least 10 flats in each series and use a standard deviation or average stack to minimize any stars or other artifacts
- ▶ Take flats for each filter and camera rotation angle

Bias Subtraction

- ▶ A bias frame is a map of the charge added to each pixel during the read out of every column
- ▶ Some chips/cameras will slightly alter the values as columns are read out, resulting in a streaking effect on images
- ▶ A bias frame is a zero second dark frame, or one taken at the highest possible shutter speed
- ▶ Bias frames may not be necessary if you are using both dark and flat frames, experiment with your setup to decided
- ▶ Bias frames are not necessary with my set-up and as such I have little experience



Calibration is probably required for almost any image you will acquire with your system

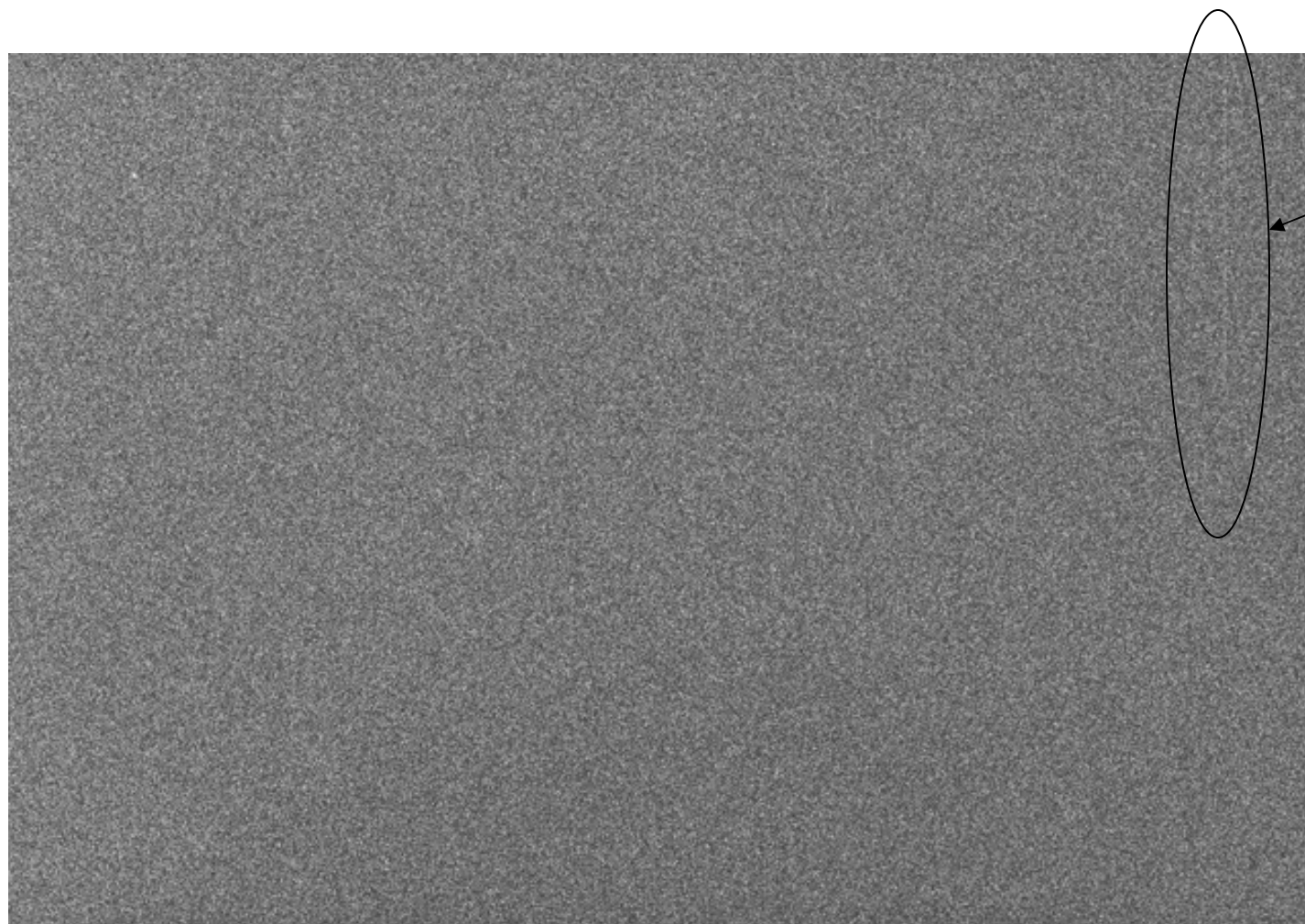


► This image is not evenly illuminated, note the shadow of the OAG prism on the top of the frame

► Hot pixels produce a noisy image



A basic dark frame looks like a field of random noise, but it is not random and will significantly improve your image

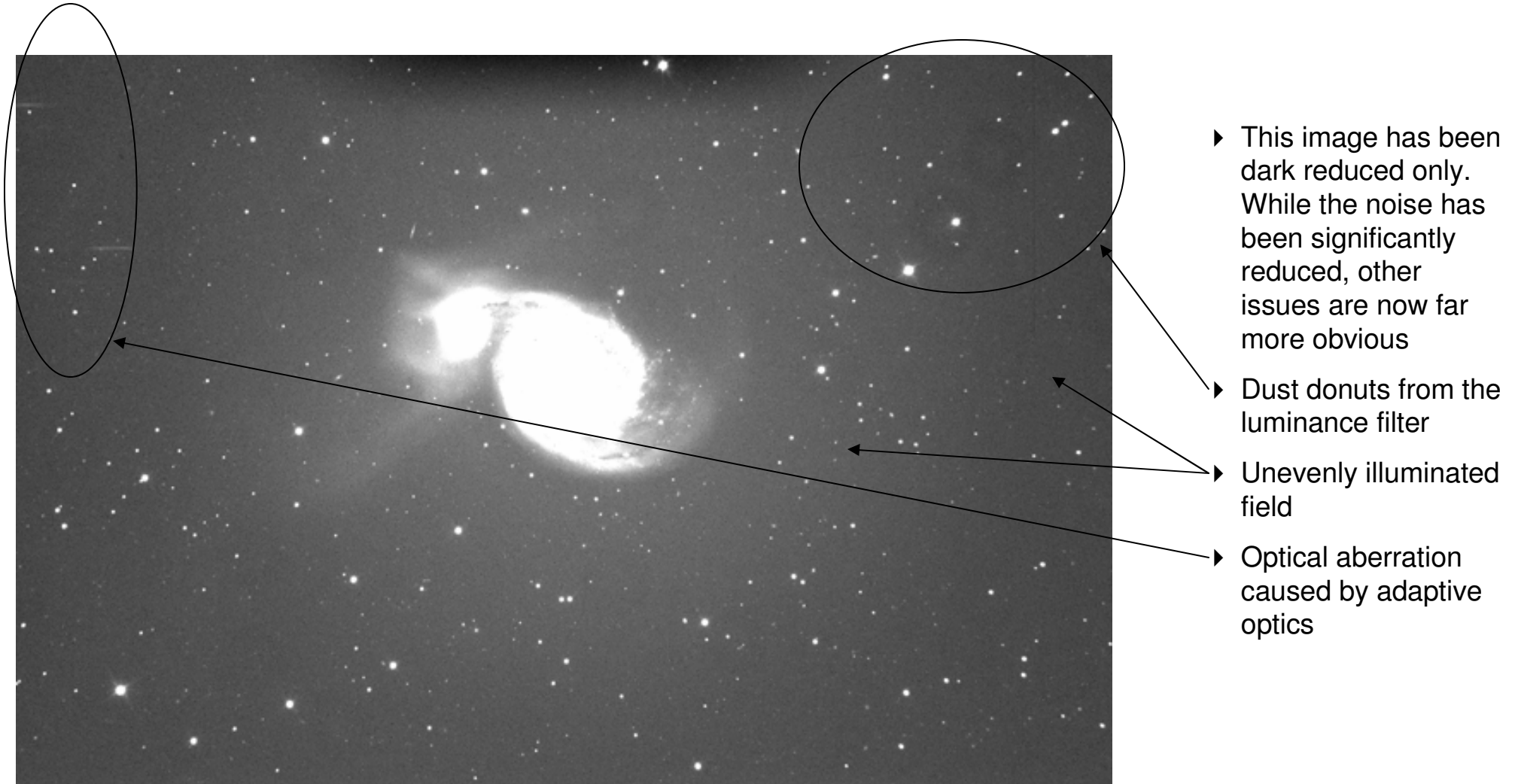


▶ In addition to noise, this dark frame shows an indication of future problems to be addressed, notably one of several bad column that results from my system having a Class 2 CCD chip



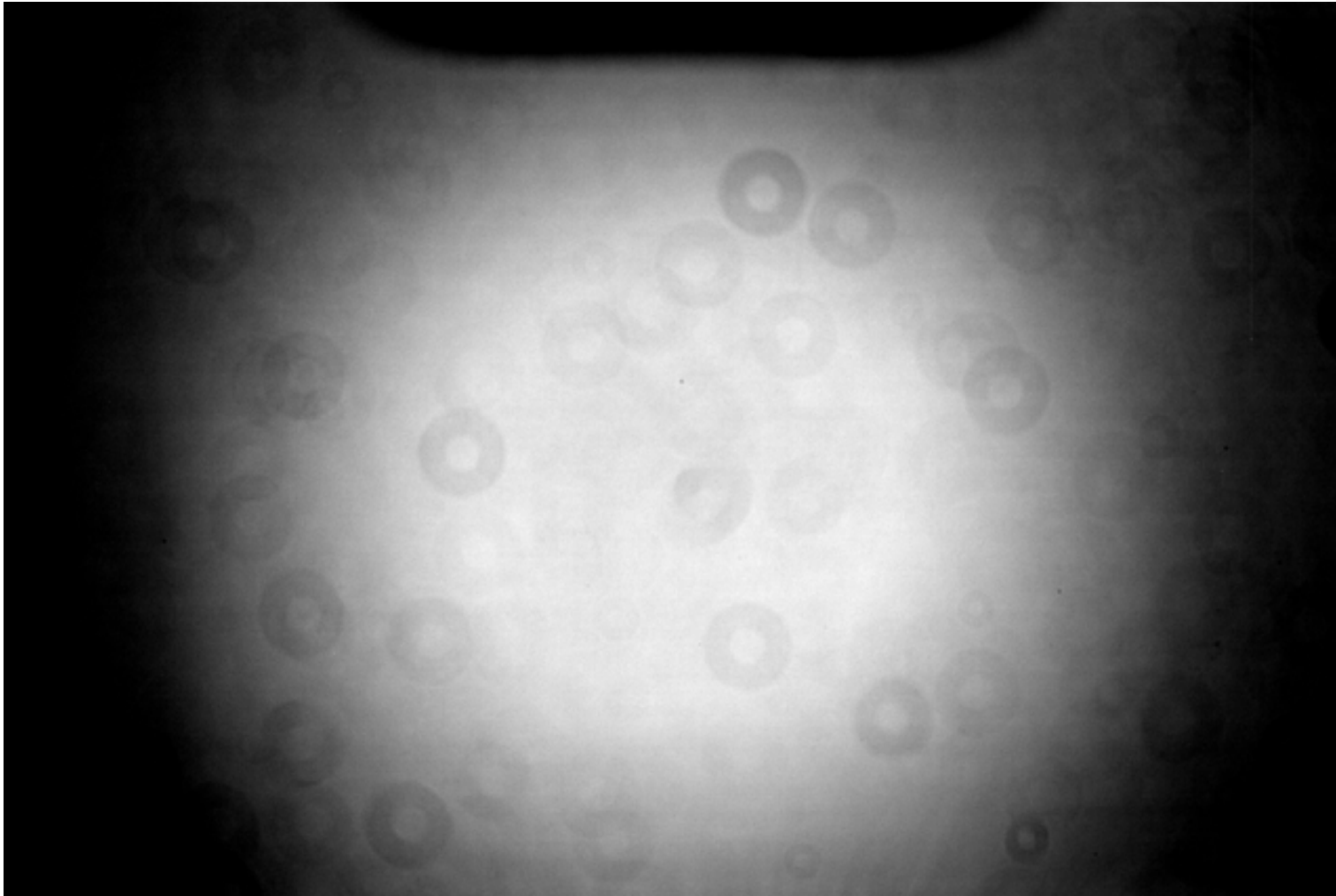
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Dark frame reduction can be done in either MaximDL, CCDSoft, most of the proprietary packages, and even in Photoshop



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A flat frame is simply a map of the flaws associated with the entire imaging system

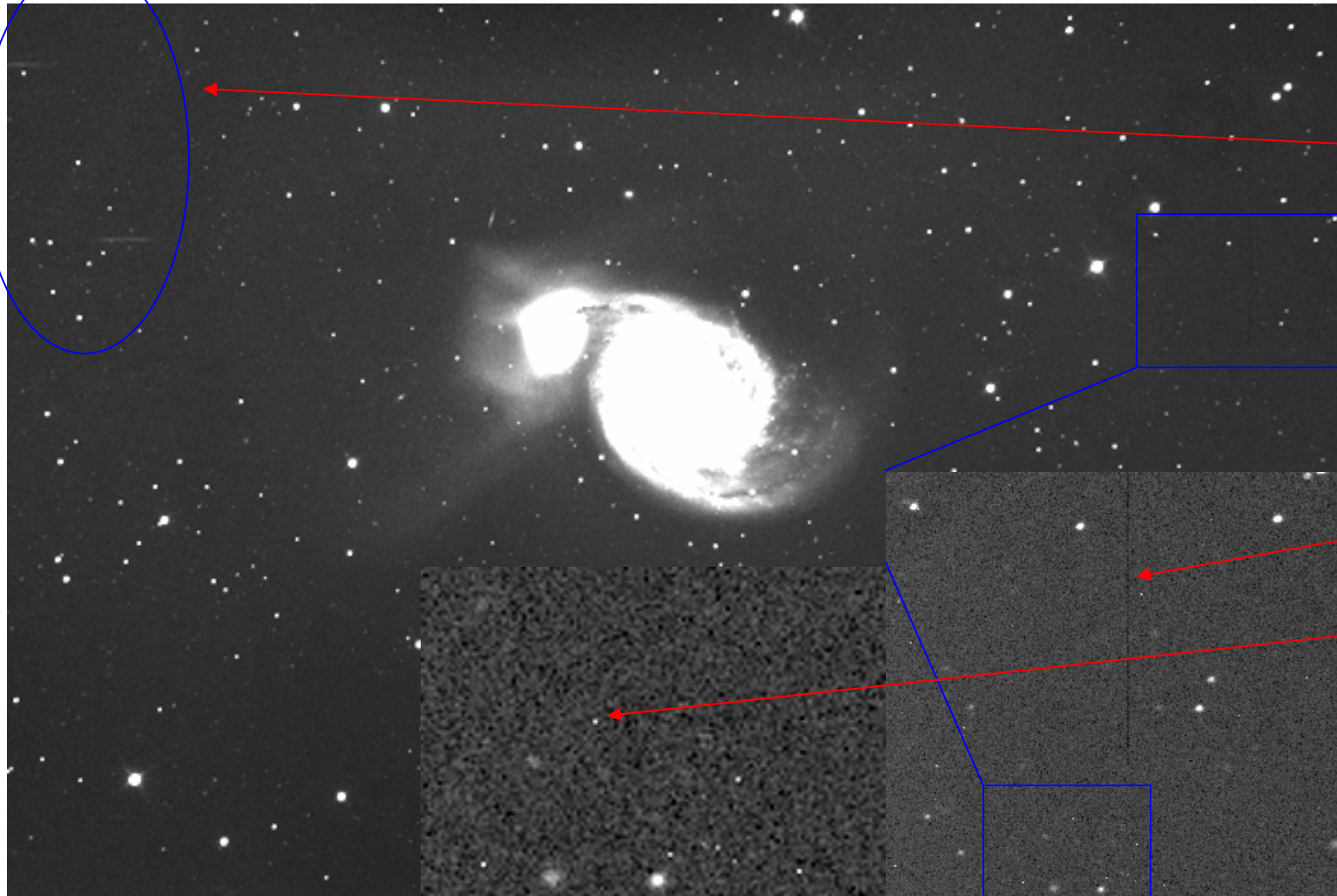


- ▶ A flat frame clearly demonstrates the lack of even illumination and dust donuts present in the optical system
- ▶ While flats can look bad, in reality this flat represents only an 11% illumination drop towards the edges of the frame. This image is heavily stretched to show all the dirty laundry



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Applying a flat frame does a great job of evening out the optical flaws, although note that it is not perfect!

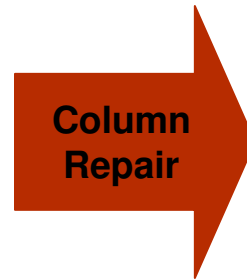
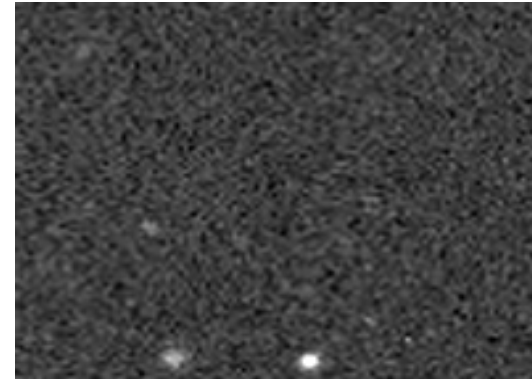
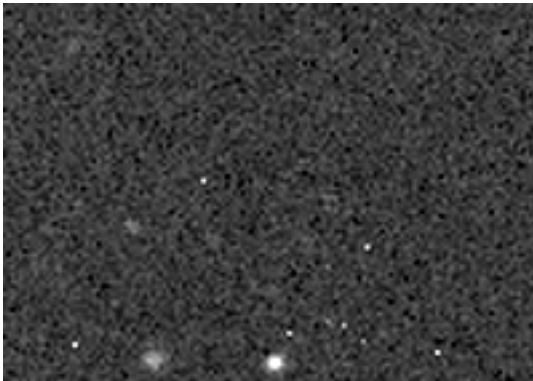


- ▶ Optical aberration caused by adaptive optics remains
- ▶ Dust donuts and uneven illumination persist at extremely low levels for reasons totally unknown to me ☺
- ▶ Column defects still exist
- ▶ Dark reduction leaves both dark holes in the image and some hot pixels still remain as well



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I typically use kernel filters in MaximDL to do a last bit of touch up on my sub frames: hot/cold pixel correction and column repair



Here is the final sub frame, fully stretched to show the lack of major flaws – the blown out core is due to this stretching



- ▶ The aberration created by the adaptive optics can not be automatically repaired, and will be dealt with during final processing
- ▶ This image is not perfectly flat fielded and I continue to struggle with obtaining and applying perfect flats. Flat fielding is in my experience by far the most difficult step!



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Properly calibrating all of your sub frames is essential to producing a high quality final image

- ▶ Each “layer” of reduction/calibration reveals more subtle flaws with the image – you can’t afford to skip any steps!
- ▶ Flat fields are less important with very fast, evenly illuminated systems that do not exhibit dust donuts as severely due to an extremely steep light cone and narrow critical focus zone
 - F4 or less systems that have an extremely even field of illumination, or where a very small imaging chip is in use, may not require flat fielding
- ▶ Build a library of dark frames to avoid wasting precious imaging time taking darks!
- ▶ DSLR users should beware of using dark frames which might create unacceptable “holes” in the image
 - Most DSLRs perform in camera or on-chip noise reduction, even when you are shooting in “raw” mode which can make taking and applying dark frames extremely difficult
- ▶ Experiment, experiment, experiment! Different set-ups will have different calibration requirements!

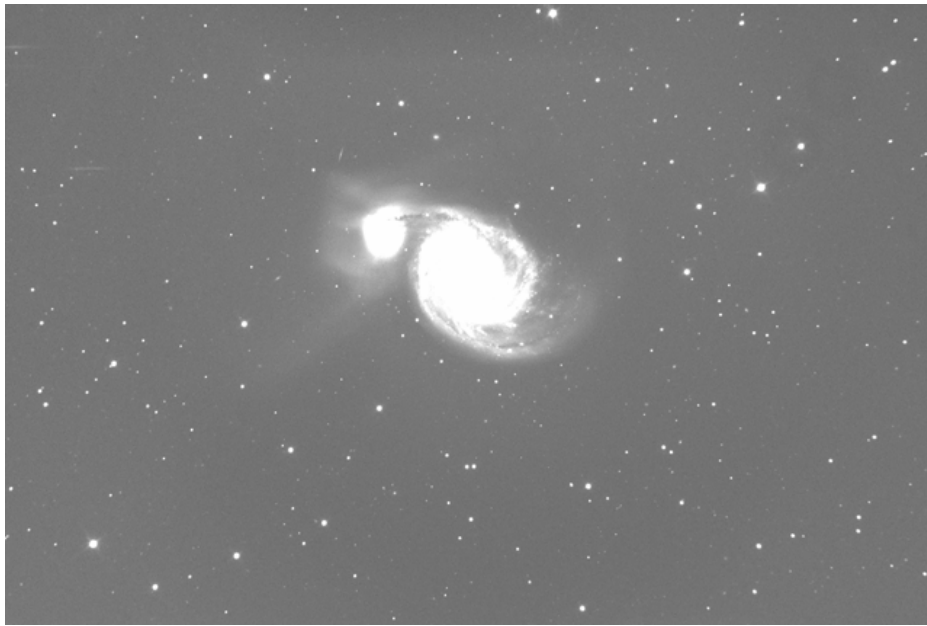


Overview

- ▶ Equipment Overview
- ▶ Software/Hardware
- ▶ Image Processing Basics
 - Calibration
 - **Selection**
 - Alignment
 - Stacking
 - Levels/Curves
 - Layer Blending
 - Assembling an RGB Image



Some sub frames will not be usable in your final stack and can significantly degrade image quality if they aren't removed



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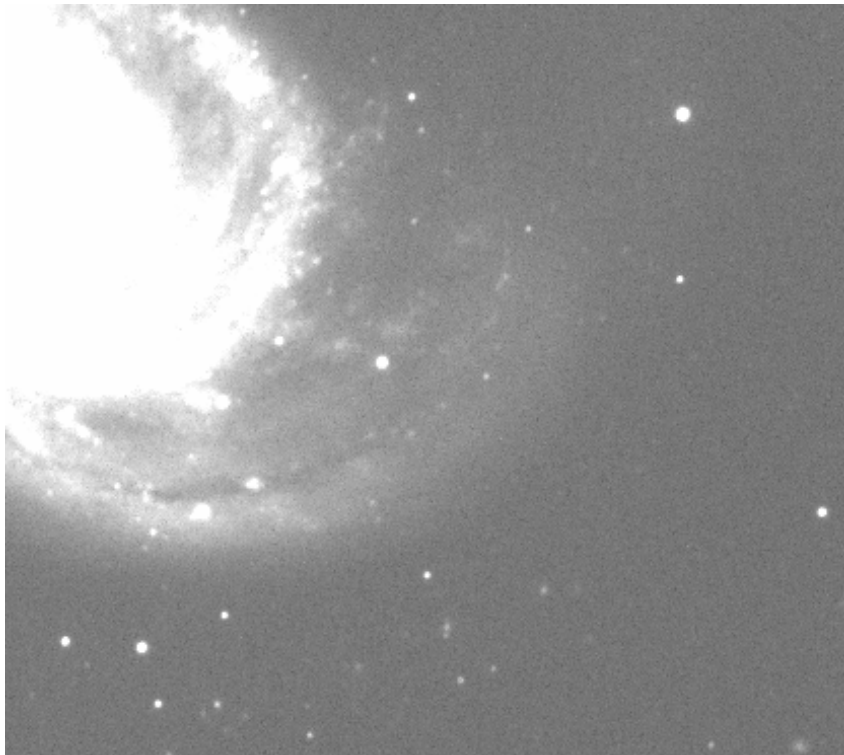


- ▶ These images only look similar, but in reality there are extremely different in terms of total quality as revealed by a more detailed inspection...

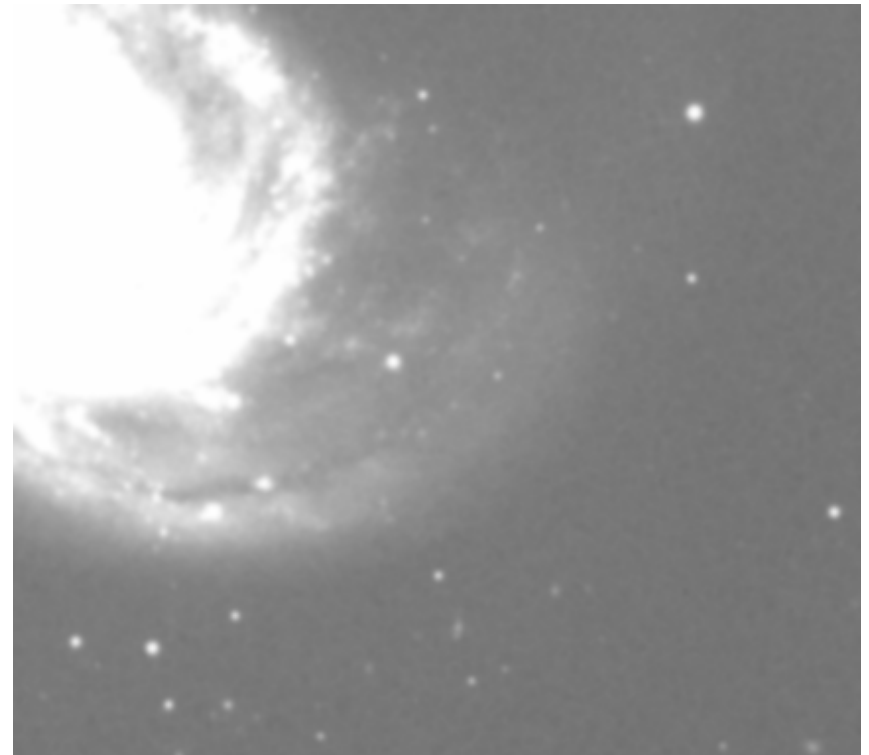


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The sub on the right suffered from either a lack of proper focus or a period of extremely poor seeing



≠



- ▶ The image on the right must not be included in the final image stack or it will significantly reduce the overall image quality of the final image



Some tools, like CCD Inspector provide an automated and totally objective way to assess the quality of a sub

Image File	FWHM	Aspect (...)	Backgro...	Contras...	Altitude	Date & Time
M51 - TDS - Lum_000000690.fit	2.24"	14	634	46.71	+75° 13' 40"	03/11/08 02:34:04
M51 - TDS - Lum_000000689.fit	2.34"	16	635	46.47	+74° 39' 10"	03/11/08 02:23:14
M51 - TDS - Lum_000000688.fit	2.40"	13	638	46.60	+73° 49' 55"	03/11/08 02:12:24
M51 - TDS - Red_000000699.fit	2.43"	15	406	42.39	+59° 41' 54"	03/11/08 05:11:23
M51 - TDS - Lum_000000687.fit	2.45"	14	649	46.55	+71° 22' 59"	03/11/08 01:48:53
M51 - TDS - Lum_000000686.fit	2.53"	14	554	44.71	+70° 01' 18"	03/11/08 01:38:03
M51 - TDS - Red_000000700.fit	2.53"	13	427	41.57	+57° 39' 37"	03/11/08 05:23:43
M51 - TDS - Lum_000000702.fit	2.54"	13	1189	43.92	+53° 23' 03"	03/11/08 05:49:09
M51 - TDS - Lum_000000701.fit	2.57"	12	726	43.67	+55° 12' 57"	03/11/08 05:38:18
M51 - TDS - Lum_000000703.fit	2.70"	11	3659	52.28	+51° 32' 44"	03/11/08 06:00:00
M51 - TDS - Lum_000000693.fit	2.91"	16	808	46.38	+72° 09' 50"	03/11/08 03:40:43
M51 - TDS - Lum_000000694.fit	2.93"	14	829	45.87	+70° 03' 50"	03/11/08 03:57:57
M51 - TDS - Lum_000000691.fit	3.18"	22	796	47.08	+75° 02' 44"	03/11/08 03:06:16
M51 - TDS - Lum_000000692 - bad.fts	3.42"	78	30315	20.49		03/20/08 13:14:56

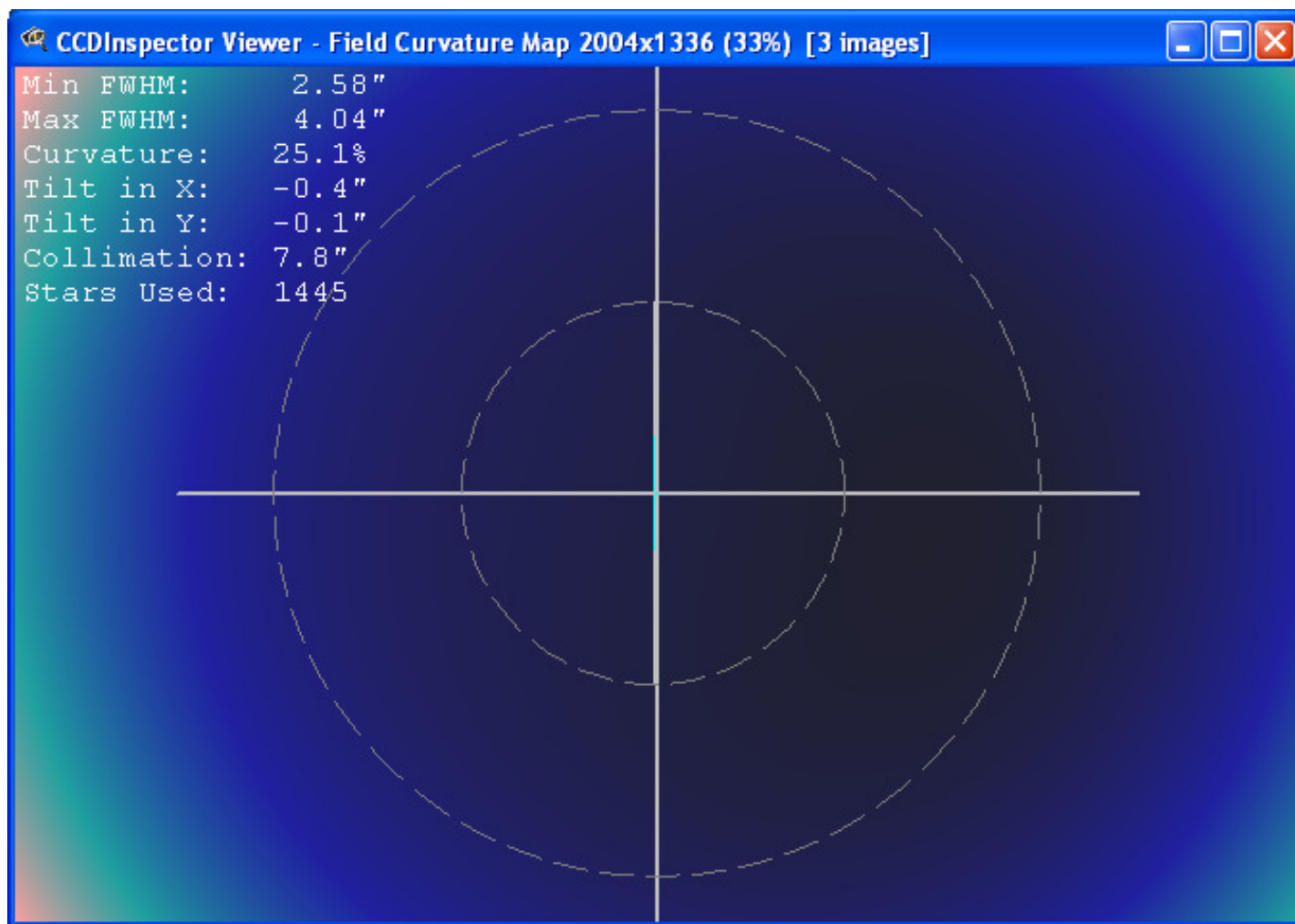
► You can clearly see the Full Width Half Max (FWHM) indicated 3.42 arc second star sizes on average, which is very poor.

► Sadly this image didn't come out all that well...the seeing was outstanding the night I took these images and my FWHM ratings should have been better!



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CCD Inspector offers some nifty additional features such as a collimation tool that can analyze your optics very precisely



- ▶ Note the off-center dark area and the red fringing on the left corners. This indicates a fairly significant tilt in the X axis which significantly degraded these images
- ▶ I verified this by manually checking the collimation the next morning
- ▶ Note: Always check and recheck your collimation after you set up your system ☺



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Overview

- ▶ Equipment Overview
- ▶ Software/Hardware
- ▶ Image Processing Basics
 - Calibration
 - Selection
 - **Alignment**
 - Stacking
 - Levels/Curves
 - Layer Blending
 - Assembling an RGB Image



Images acquired can vary in alignment for a variety of good and bad reasons

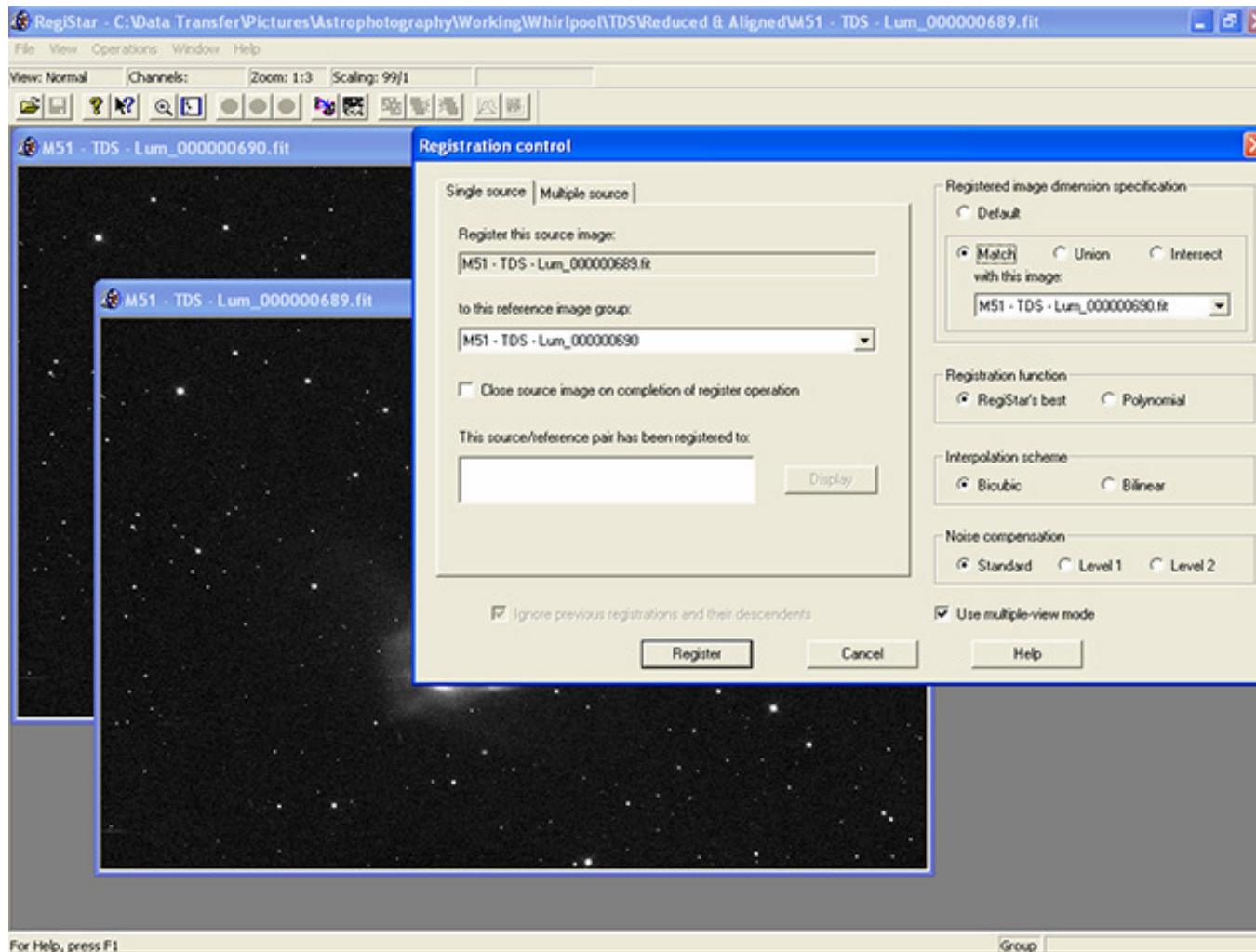


- ▶ **Dithering** is an intentional slight shift in the image between frames so that bad pixels and artifacts do not exactly align after a star alignment. This allows for standard deviation combining to dramatically reduce those problems
- ▶ **Pointing problems**, and **polar misalignment** can cause objects to drift during a long sequence of exposures
- ▶ As you can see, failure to align properly results in total disaster!



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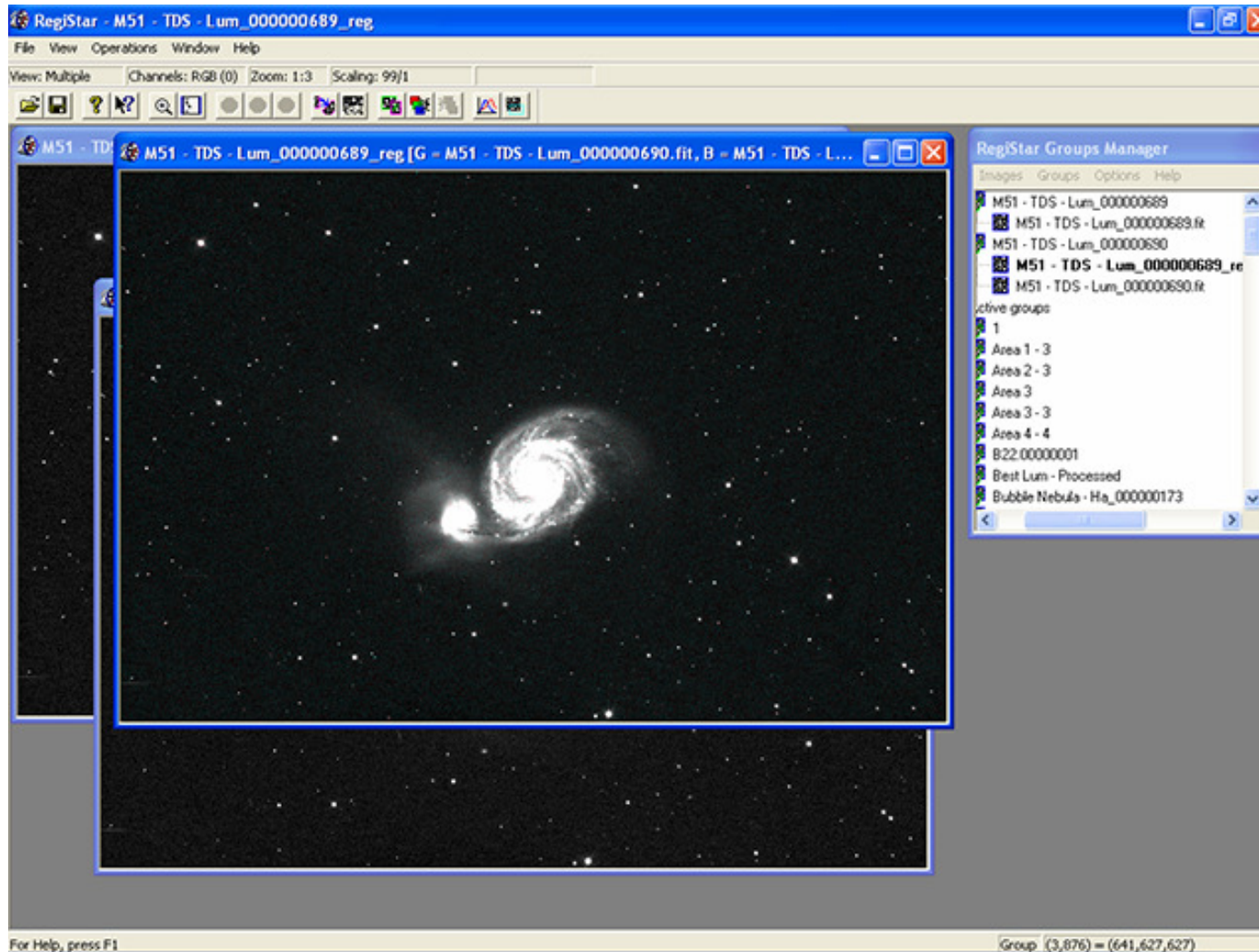
My preferred software program for star alignment is Registar, although MaximDL, CCDSoft and other programs can work well



- ▶ Failure to use well calibrated images is probably the #1 reason that image alignment software fails
- ▶ High quality data that isn't terribly out of alignment in the first place will put much less stress on your alignment software
- ▶ At \$99 Registar really is hands down the best image alignment software available for deep sky images
- ▶ Registar can align images at different scales and with only 15% of the images overlapping, which is critical for creating mosaic images!



The resulting aligned images are ready to stack with your favorite software



- ▶ The resulting images are perfectly aligned with the master reference frame
- ▶ Batch processing of entire directories is possible expediting the alignment process



Night Sky Photography by Jeff Lunglhofer

Overview

- ▶ Equipment Overview
- ▶ Software/Hardware
- ▶ Image Processing Basics
 - Calibration
 - Selection
 - Alignment
 - **Stacking**
 - Levels/Curves
 - Layer Blending
 - Assembling an RGB Image

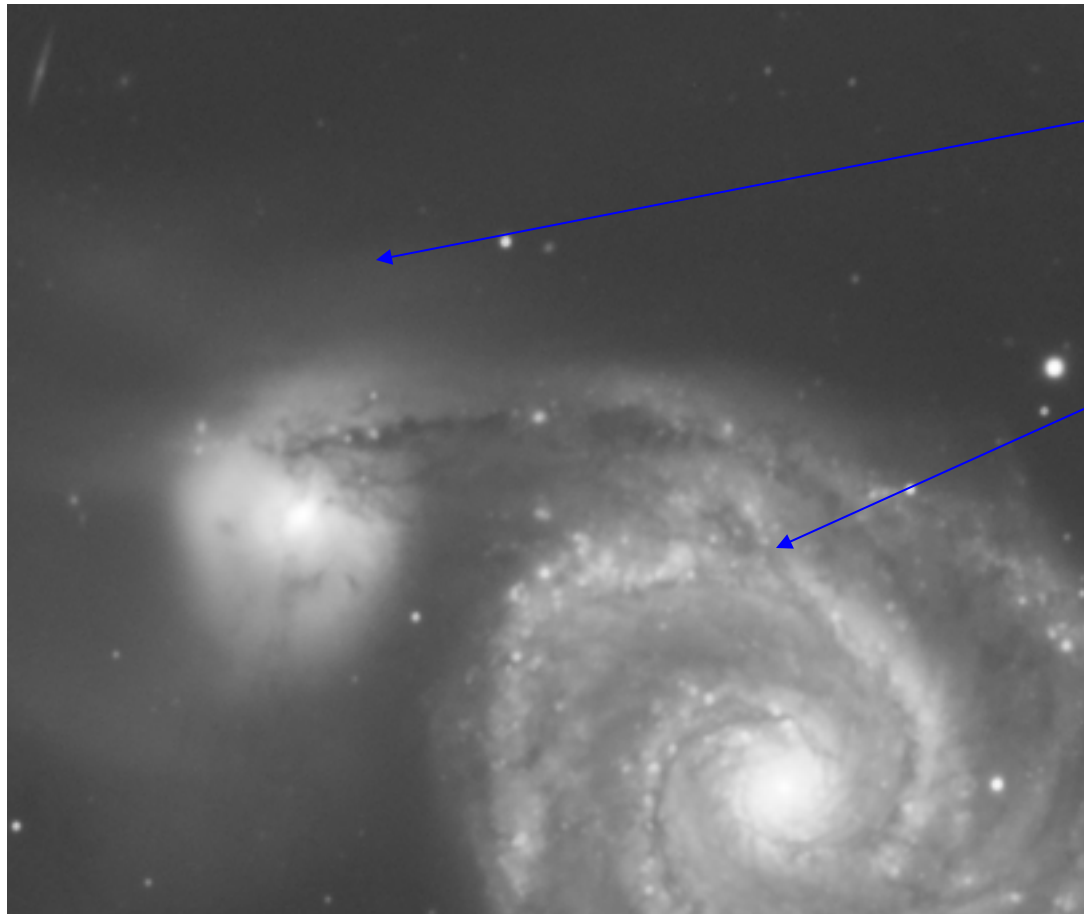


There are a wide range of options and software packages available for stacking images, I prefer Ray Gralak's free "Sigma" tool

- ▶ Sigma combine works only with FITS files, not with DSLR raw files or TIF files
- ▶ Median Combine: Probably the most useful method of combining images, this technique relies on complex algorithms to identify inconsistencies between frames and toss out the bad data, retaining only the data that occurs across all the provided images
 - This powerful tool can eliminate meteor/satellite streaks and even aircraft light trails in sub frames
 - Dithered images benefit dramatically from this stacking method since some hot/cold pixels will move between dithered frames and be eliminated during median stacking
- ▶ Averaging: A simple yet extremely effective method for combining images where the signal for each pixel is simply averaged across all the frames. Since most thermal noise is somewhat random this results in a gradual increase in the signal to noise the more images are in the stack
- ▶ Standard Deviation: Another excellent method for combining images, particularly powerful on subtle areas of nebulosity where the signal is extremely low. The standard deviation for every pixel is calculated and used as the final value
- ▶ ***There is no one method of stacking that is the best, and I often find that one works better than another, even on different areas of the same target!! Those instances require layer blending to get the benefits of both. You must experiment with different method for every image you process!!!***



The following portion of our image has been averaged in Sigma and been adjusted using curves in Photoshop

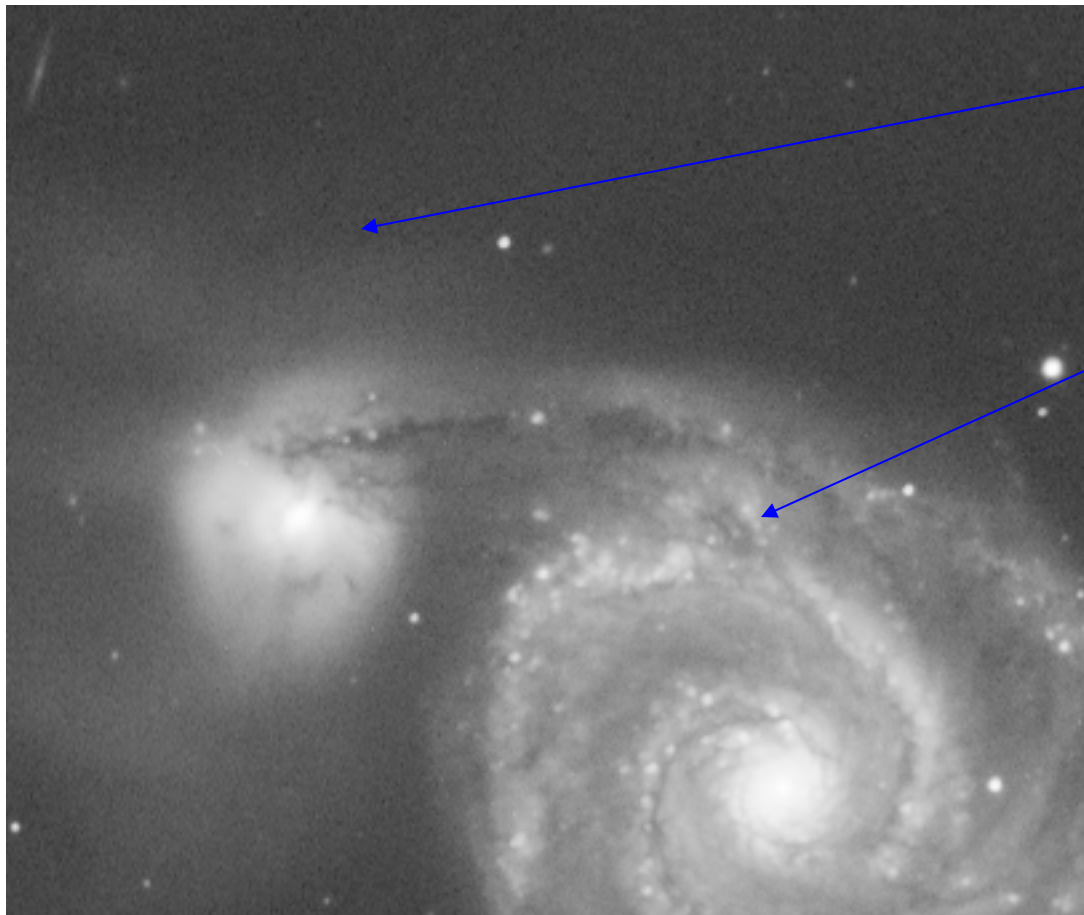


- ▶ Averaging almost always produces the smoothest results, particularly in areas with very faint signal
- ▶ Sharpness suffers, however as no data is rejected allowing bad data to reduce the quality of the better data in the image



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The following portion of our image has been median combined in Sigma and been adjusted using curves in Photoshop

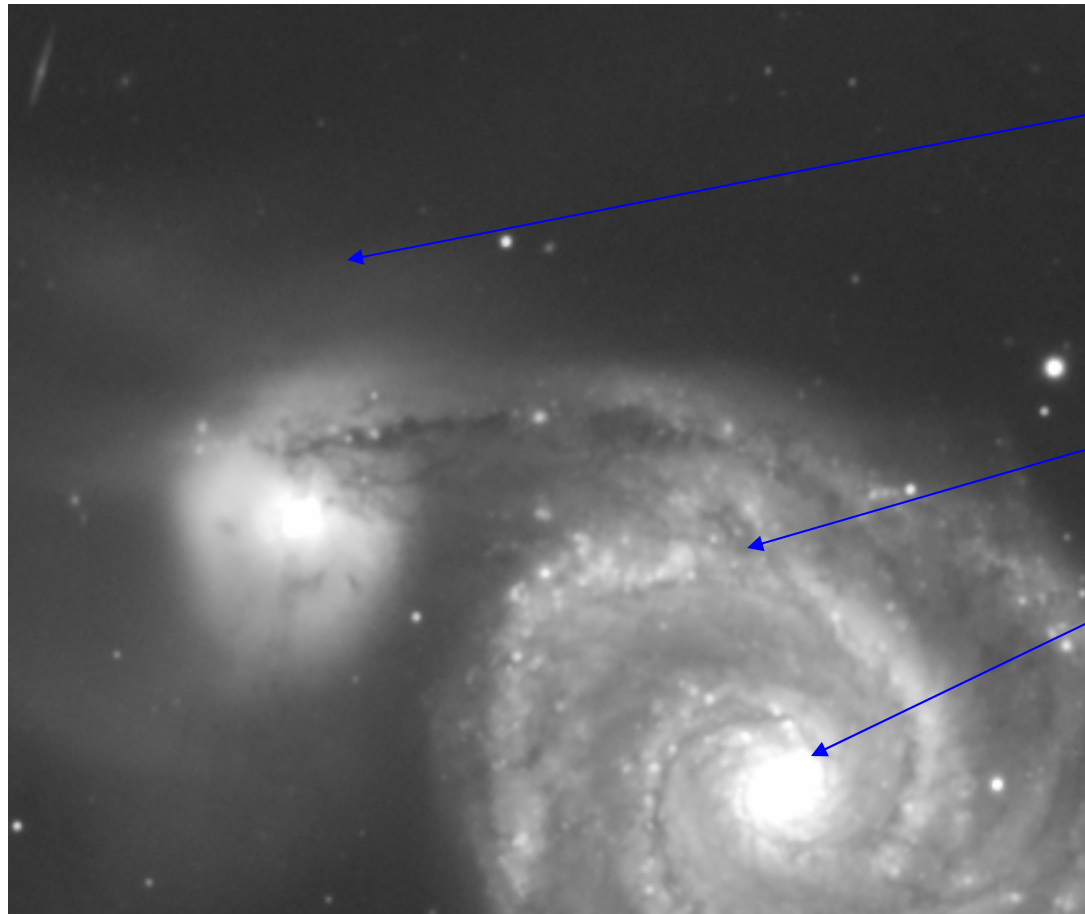


- ▶ Smoothness has really suffered in the dim areas with lots of noise showing through
- ▶ In this case a median combine has produced a sharper image in the brighter areas



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The following portion of our image has been standard deviation combined in Sigma and been adjusted using curves in Photoshop



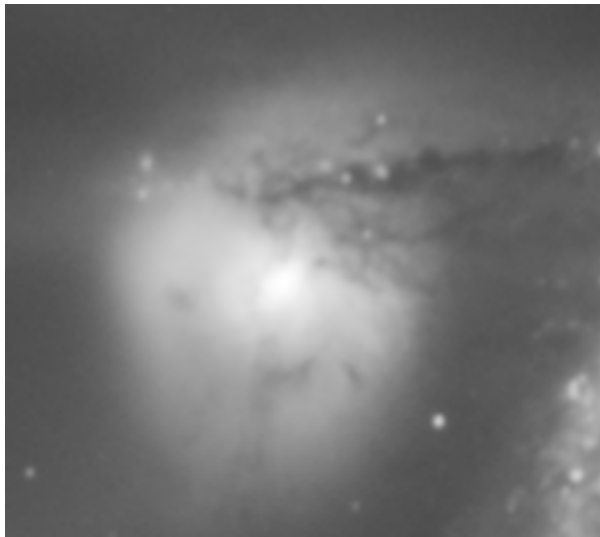
- ▶ For this image a standard deviation stack is clearly the best in almost every area, dim areas as noted here are very smooth
- ▶ The moderately bright areas are very sharp with minimal noise
- ▶ The brightest areas of the image, however, are oversaturated and blown out, with the detail from these areas lost



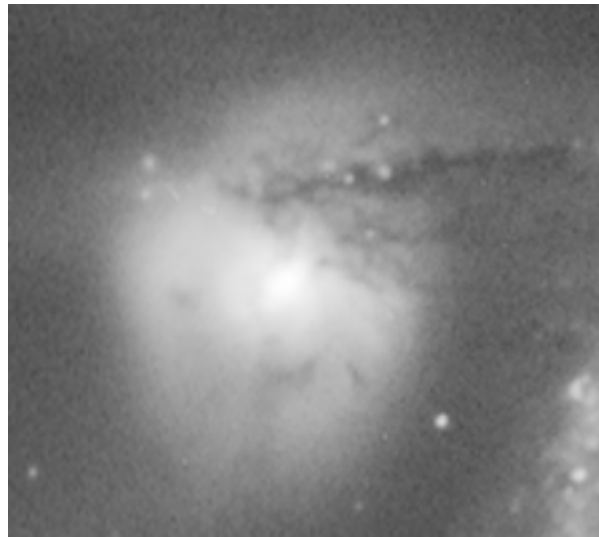
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Taking a look at the details of the image, we can see that averaging is best for the brightest areas and standard deviation for the rest

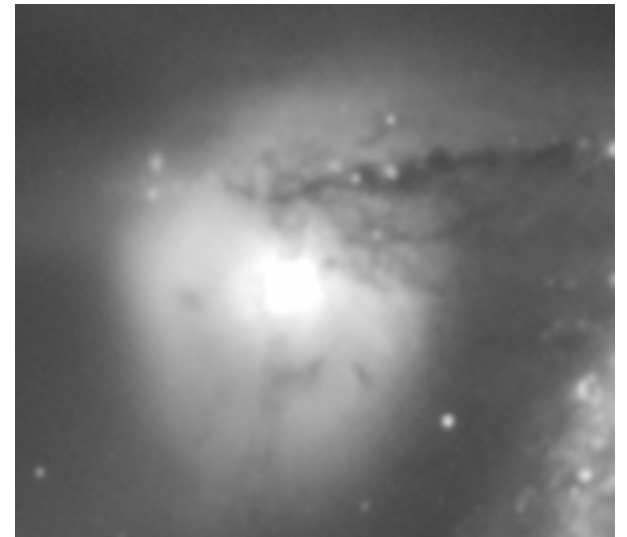
Average



Median



Standard Deviation



Overview

- ▶ Equipment Overview
- ▶ Software/Hardware
- ▶ Image Processing Basics
 - Calibration
 - Selection
 - Alignment
 - Stacking
 - **Levels/Curves**
 - Layer Blending
 - Assembling an RGB Image

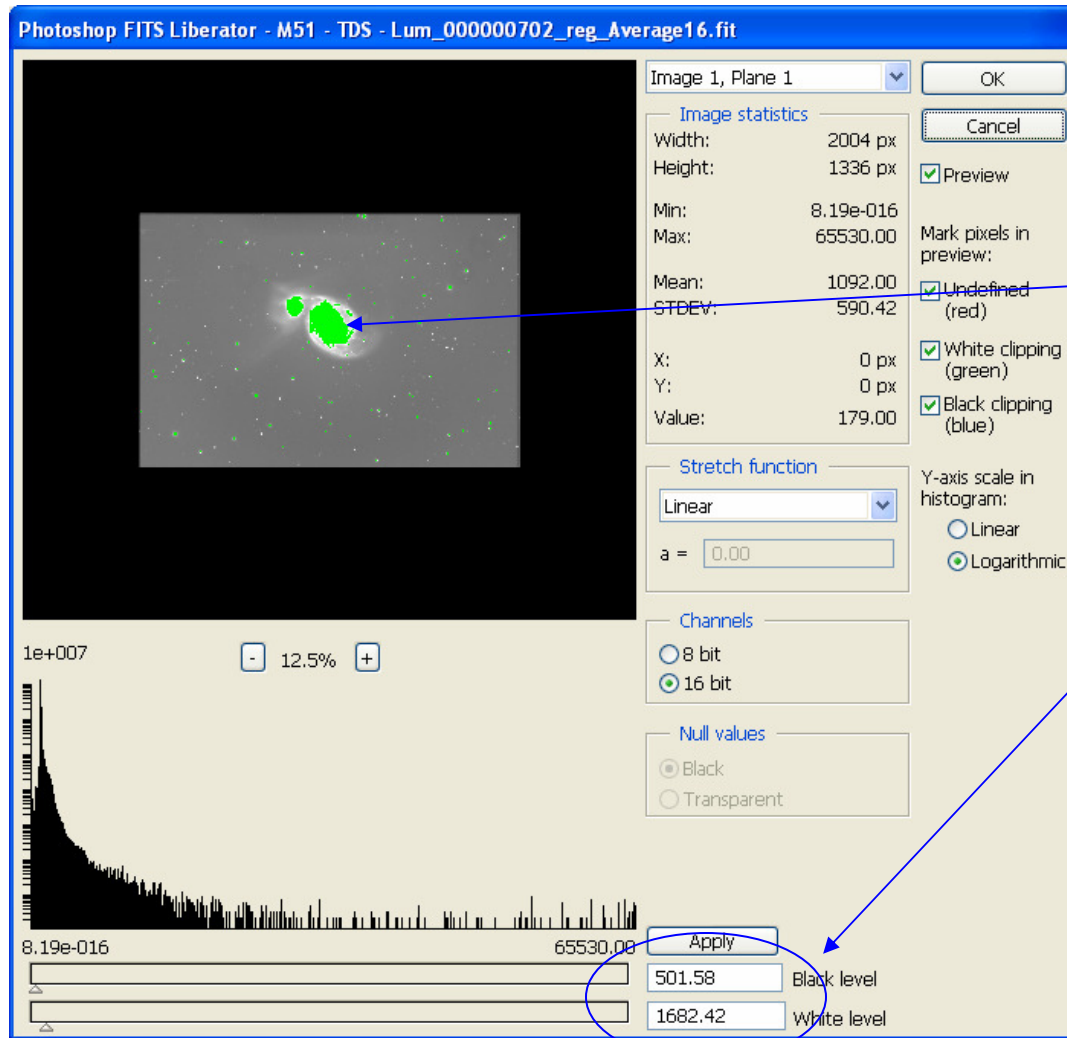


Three of the most powerful tools in Photoshop CS or better are Levels, Curves, and Layers

- ▶ Levels is simply a way of adjusting the black and white point - the blackest and brightest portion of an image. This is the tool used to perform a “stretch of data” which effectively means to take a small slice of the data in an image and stretch it across the entire available dynamic range
 - Stretching is very useful for astrophotography since usually only a small portion of the available range actually contains data relevant to the object being photographed
- ▶ Curves is a more complicated way of teasing more signal out of an image by selectively brightening only a portion of the entire light data “curve” while progressively affecting the rest of the range less and less as you get further from the selected point of the light curve
 - This is probably my most heavily used function in Photoshop and I have created a “light curves” action that works for the majority of astrophotography I’ve ever taken and lets me quickly apply a slight curve over and over to an image
 - Curves can be much more powerful than simple levels since a properly applied curve adjustment will not blow out the brightest areas of the image, causing data loss, or overly brighten the darkest areas. Thus it’s a very precise way to impact the contrast of the image without causing damage.
- ▶ Layers are a critical tool for layer blending, which I will discuss in the next section, and are also necessary to assemble an LRGB image in Photoshop



Here we are using the free fits liberator tool to open up a raw average stack of our image using the entire range of data available

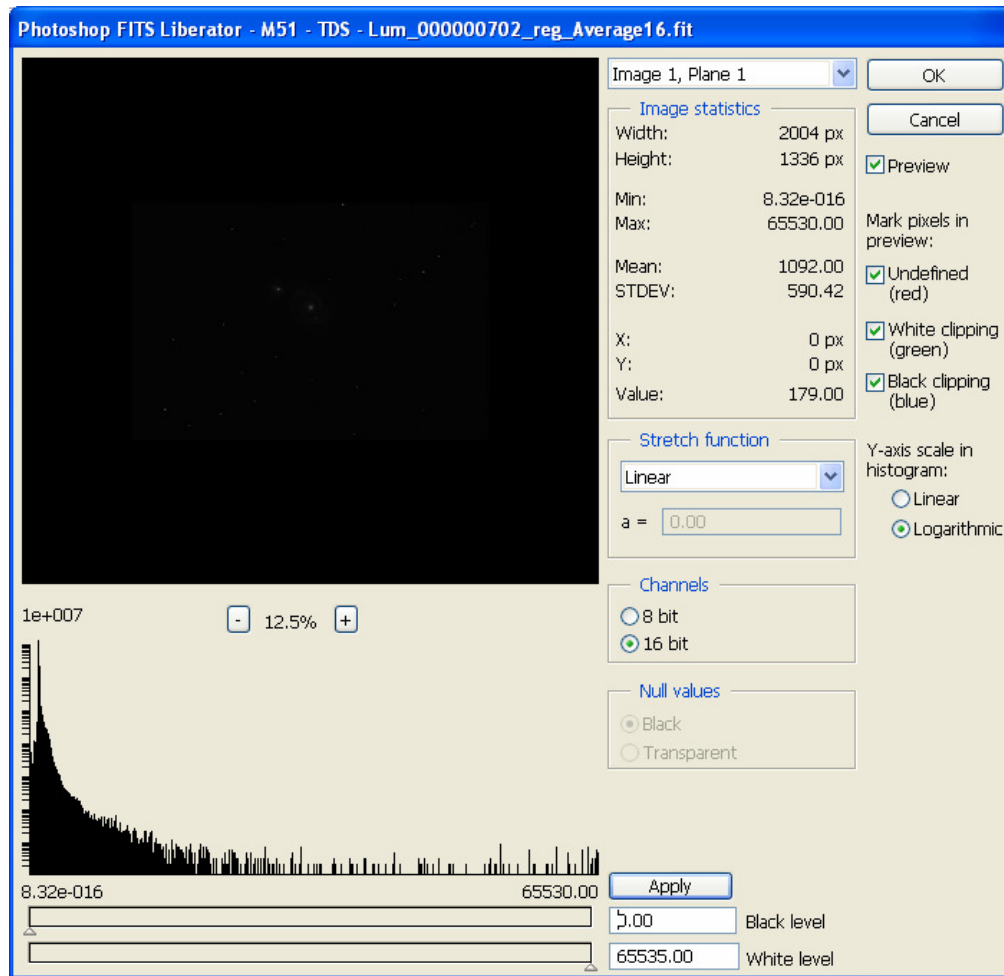


- ▶ Fits Liberator will automatically stretch the image when you use it to open a file
- ▶ The brightest areas of the image, however, are oversaturated and blown out, with the detail from these areas lost
- ▶ We do not want anything processing our image but us and Photoshop, so we will undo this by setting the black level to 0 and the white level to 65535, which is the highest value possible for a pixel in a 16 bit image



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Here we are using the free fits liberator tool to open up a raw average stack of our image using the entire range of data available

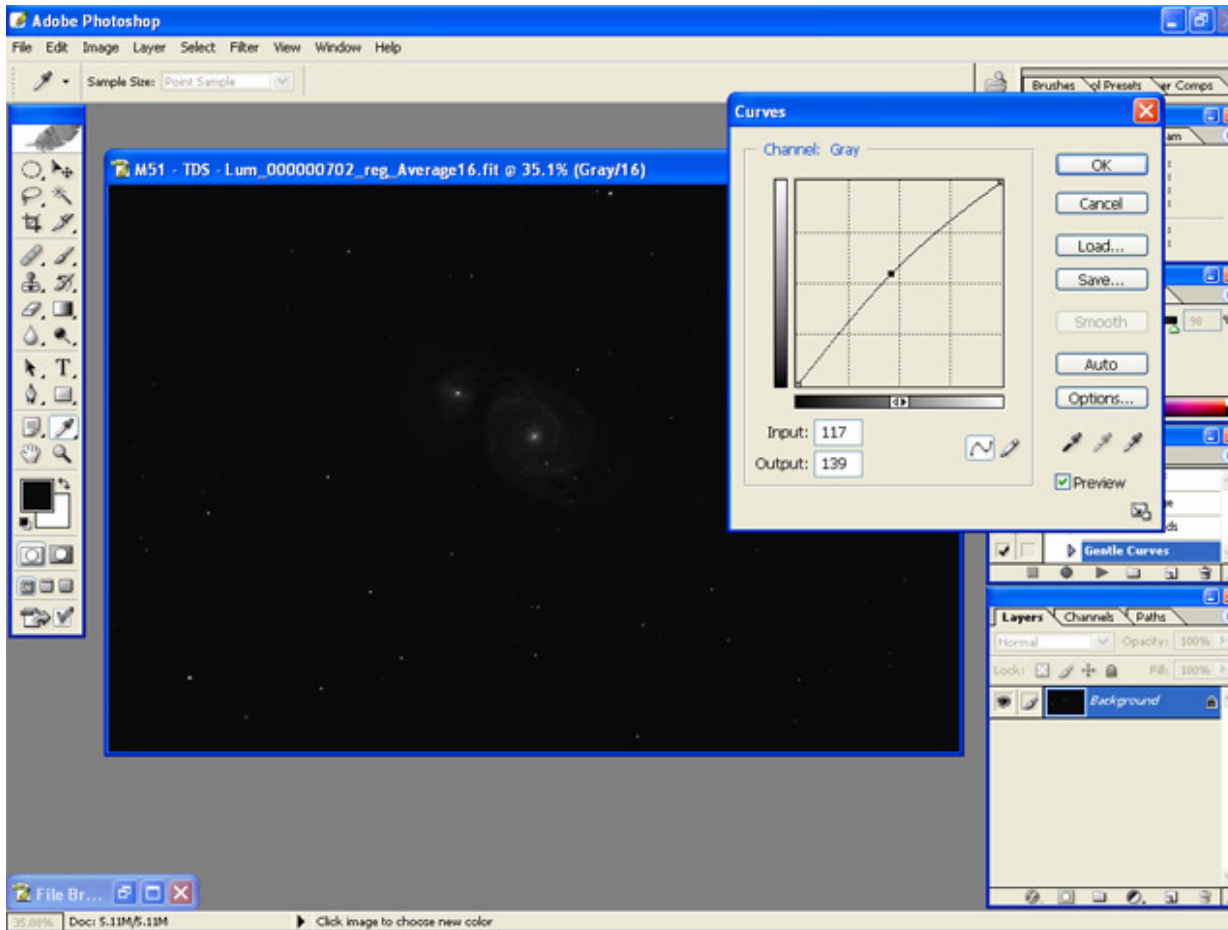


- Now that we have properly set out black and white points, the image looks entirely black. . .but don't worry, it's not really all black, the signal is just very low and our monitor isn't able to display it



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Here we are using the free fits liberator tool to open up a raw average stack of our image using the entire range of data available

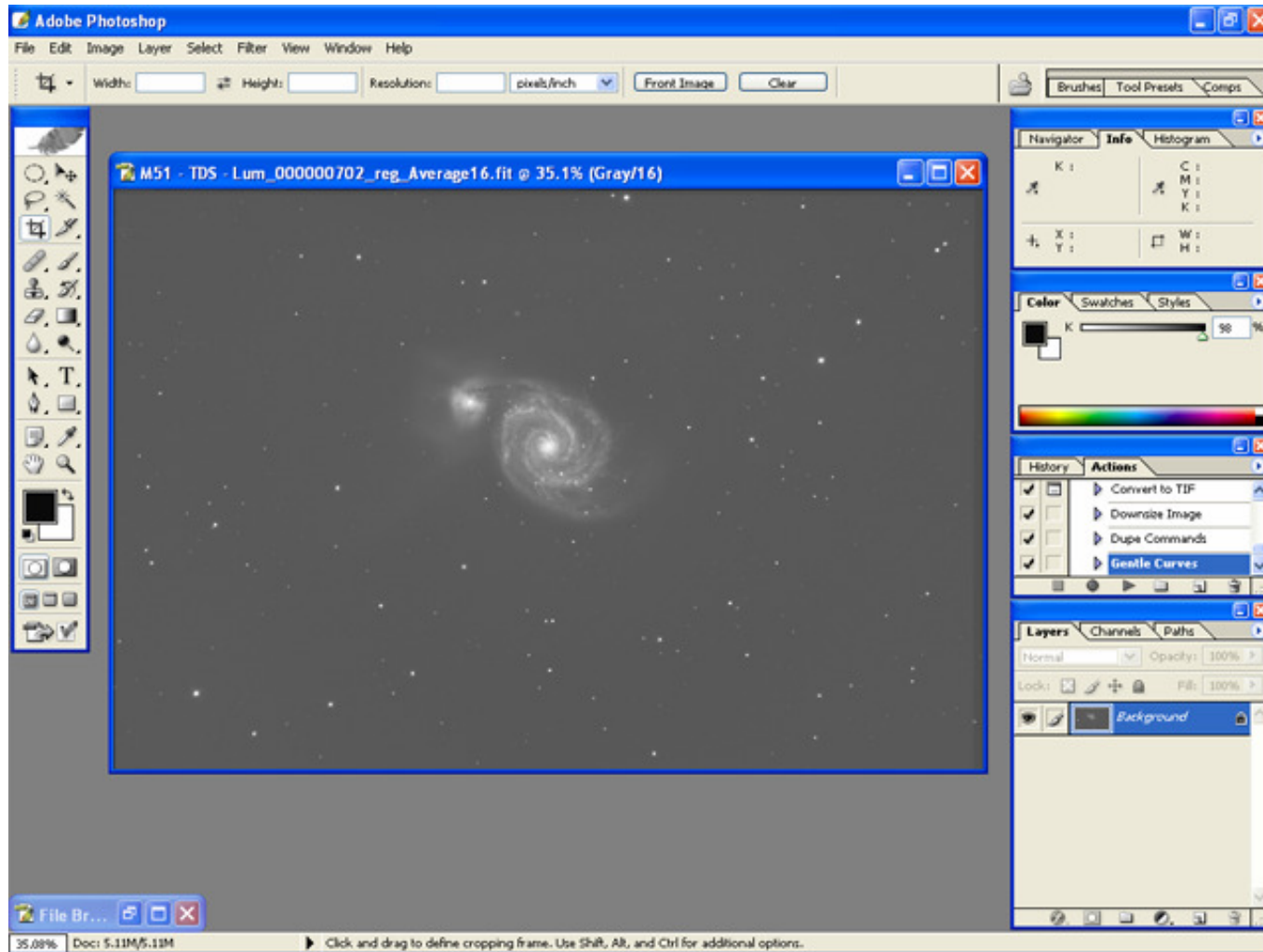


- ▶ Our first set of actions is to gently boost the signal in the image by adjusting the curves in very small increments.
- ▶ Resist the temptation to pull it up to fast as you can blow out the brighter areas and overly brighten the dark regions
- ▶ The trick is small changes repeated over and over until the dark areas begin to become too bright
- ▶ I use the action recorder to create a “Gentle Curves” action to make this a one click operation as I might use 15-20 curve functions at a time

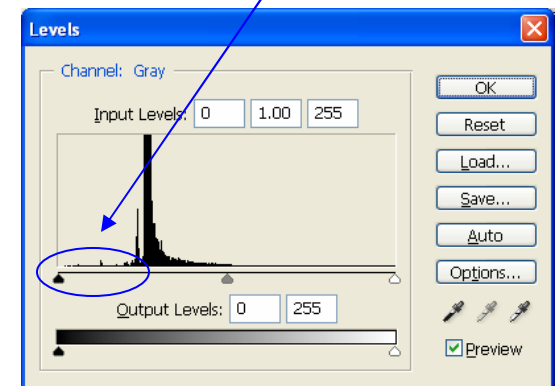


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Here we are using the free fits liberator tool to open up a raw average stack of our image using the entire range of data available

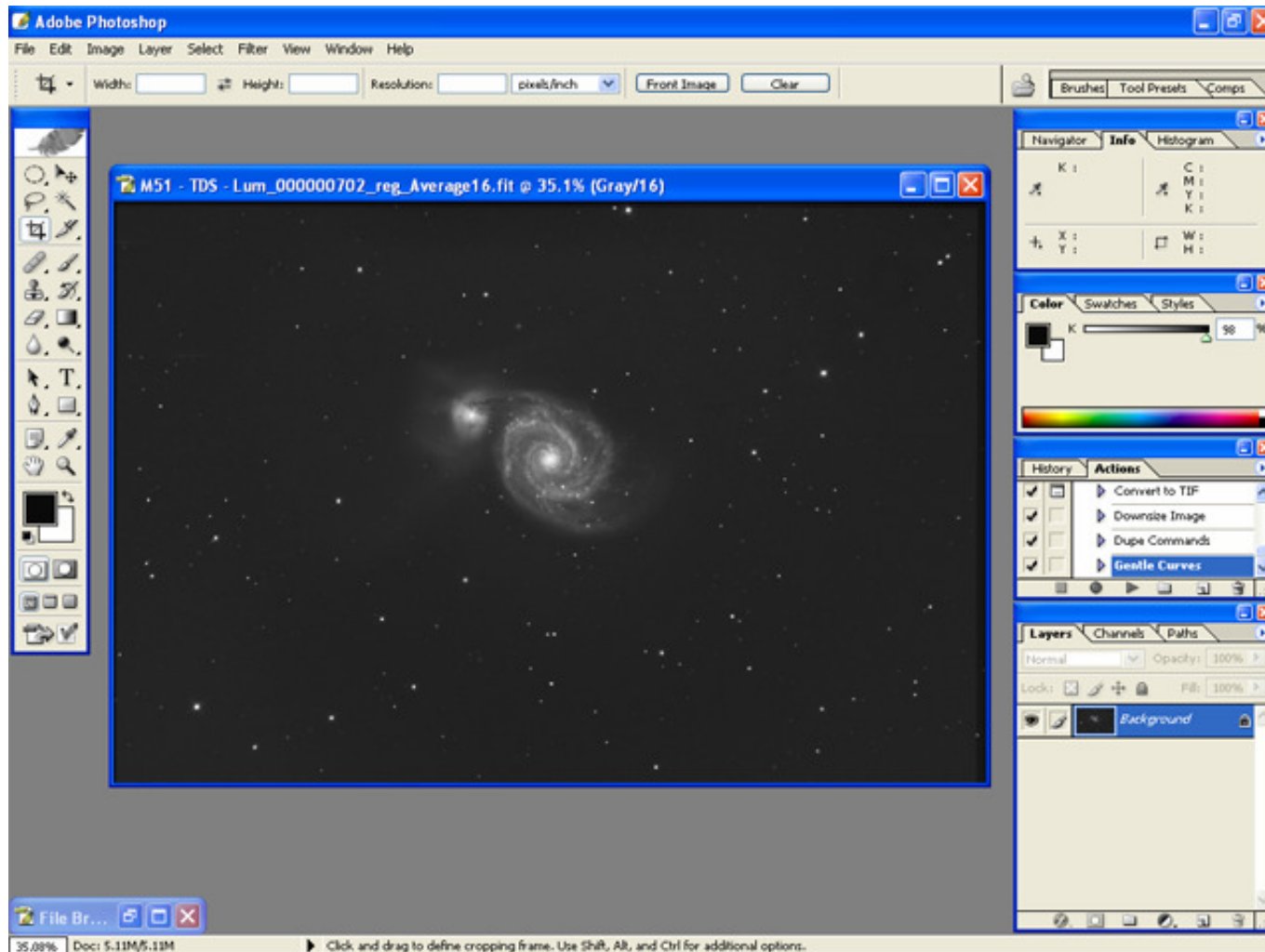


- ▶ In this case after about 15 applications of curves my dark areas are beginning to brighten to an unacceptable level
- ▶ My next step is to clip the black point, dropping the background brightness, note that it is too low and there is a lot of wasted space on the histogram



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Here we are using the free fits liberator tool to open up a raw average stack of our image using the entire range of data available



- ▶ Clipping the black point brings down the total brightness of the image and in particular drops down the dark areas back to the near-black levels where they belong
- ▶ Now we use our curves to bring out more detail in the image



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Here we are using the free fits liberator tool to open up a raw average stack of our image using the entire range of data available



- ▶ Now we have a good image that we can apply the finishing touches to
- ▶ In this case we discovered earlier that our standard deviation master image was the best overall, but suffered from a blown out core.
- ▶ Let's explore ways to repair that damage and get the best of both the standard deviation and average master stack



Night Sky Photography by Jeff Lunglhofer

Overview

- ▶ Equipment Overview
- ▶ Software/Hardware
- ▶ Image Processing Basics
 - Calibration
 - Selection
 - Alignment
 - Stacking
 - Levels/Curves
 - **Layer Blending**
 - Assembling an RGB Image

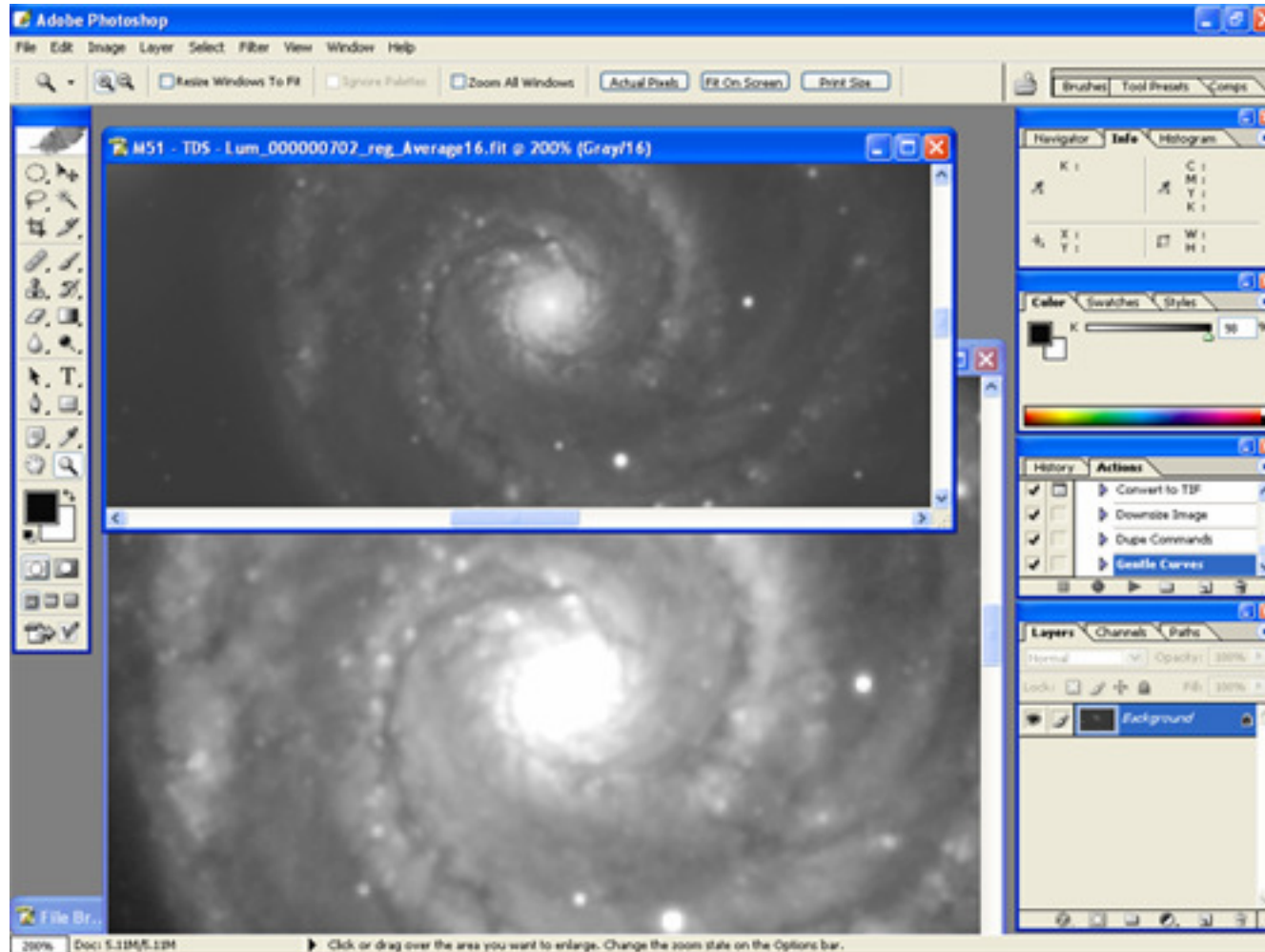


Layer blending is a powerful way to leverage a processing techniques that may benefit only a particular portion of an image

- ▶ Often a technique that benefits a dim nebulous area will significantly damage a brighter portion of the image, or vice versa
- ▶ Dim areas require more curves and stronger curves to fully pull out all the available data, but those will destroy the brightest portions of an image and can result in highly bloated stars
- ▶ Unsharpening, another powerful tool can be a huge benefit to an a brighter area with strong signal, but will only bring out the noise in dimmer areas of the image
- ▶ Layer blending is also useful for color processing, and allows you to “paint” brighter colors into specific areas of the image without impacting the rest of the image
- ▶ Layer masking, while powerful, might be considered “cheating” by some as it alters the “true” representation of the image...but given the amount of processing that goes into every astrophotograph, I have difficulty accepting this objection 😊



Layer masking can allow us to artfully blend two images together to bring out the best in each

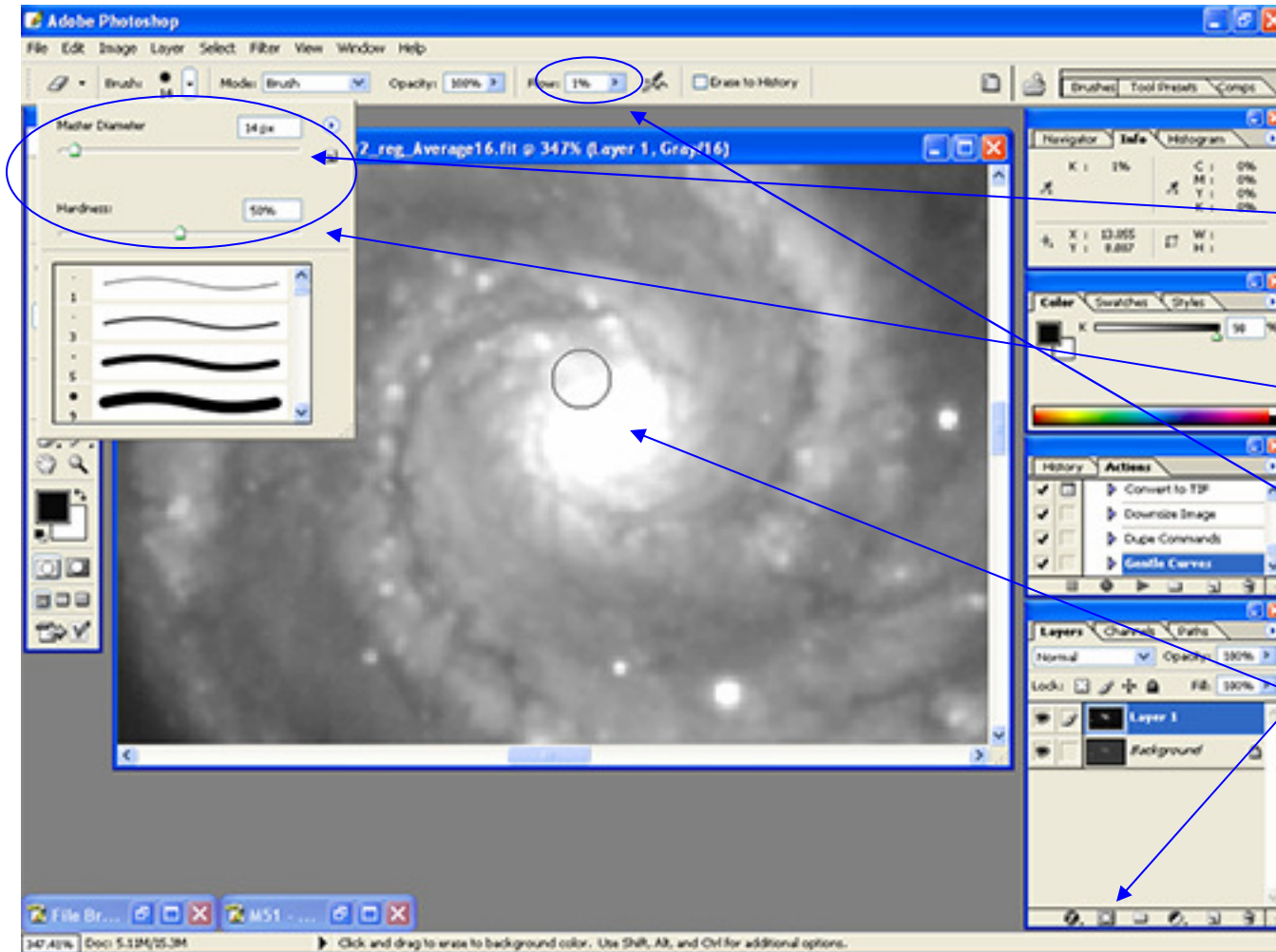


- ▶ The top image is our average master stack that has good detail all the way in towards the core of the image
- ▶ The bottom image is our standard deviation master stack that has the best detail in the spiral arms and smoothness in the dimmer areas, but a totally blown out core
- ▶ We start by copying the standard deviation image on TOP of the averaged image
- ▶ The result is a two later image, with the standard deviation image on top of the averaged image



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Layer masking can allow us to artfully blend two images together to bring out the best in each –

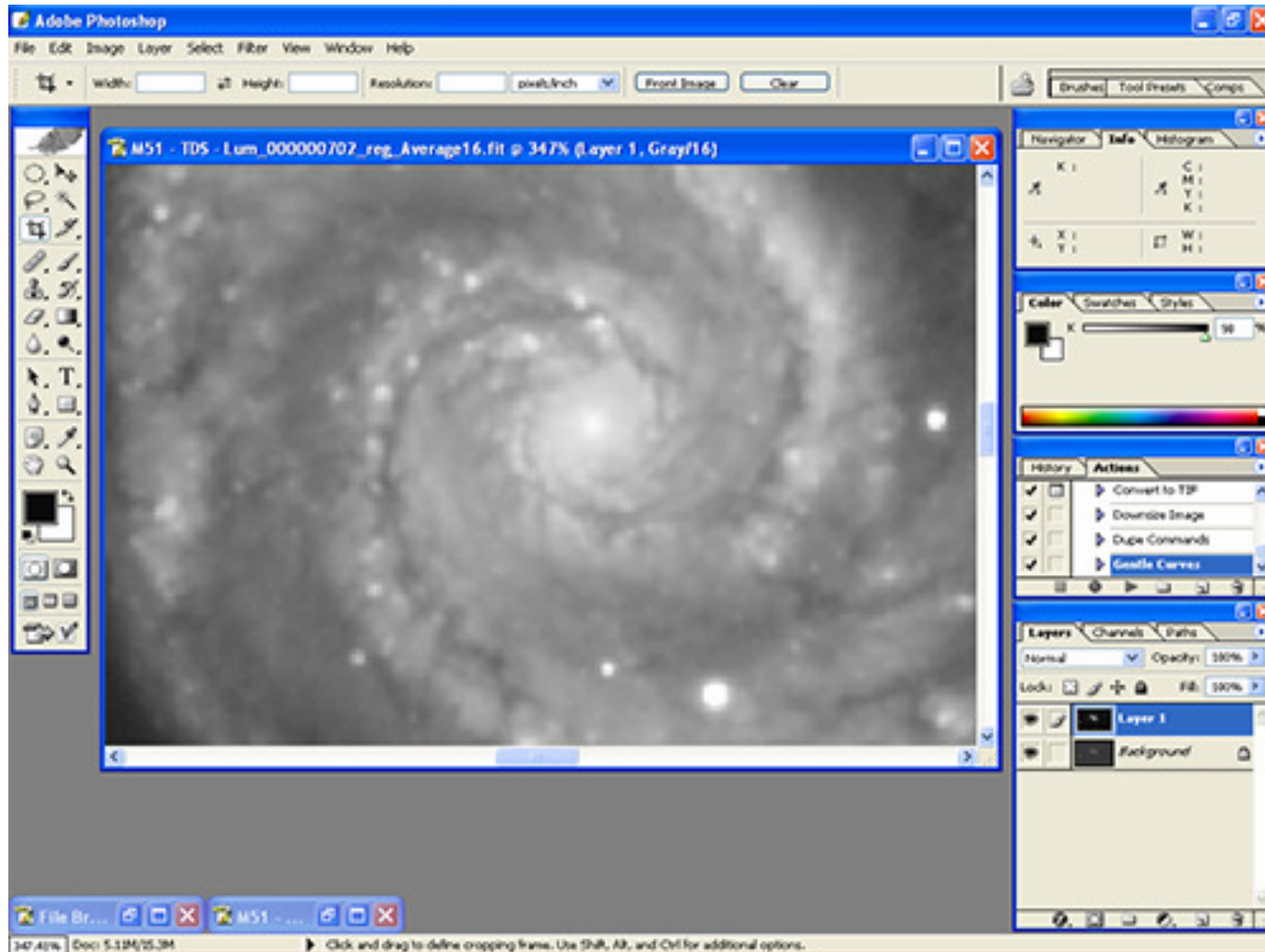


- ▶ The paint brush is our weapon
- ▶ We set our brush diameter to a reasonable size for the portion of the image we will be working on
- ▶ We set the brush softness to around 50% to avoid hard edges on our strokes
- ▶ We modify the flow setting to 1% to make all strokes very light
- ▶ We create a layer mask associated with our top image
- ▶ We then use our brush with the color black to gradually erase away the foreground image, allowing the image behind to show through, or white to reverse the effect



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Careful use of layer masking lets the underlying image show through the image on top, giving us an ideal blend



- ▶ The center is no longer blown out, but the average image is only used for this portion of the image
- ▶ Check the entire image for areas where the underlying image has better data, and don't hesitate to “brush it in”
- ▶ Flatten the image when you are complete



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Our semi-final image is a nice combination of both images that demonstrates the best of both

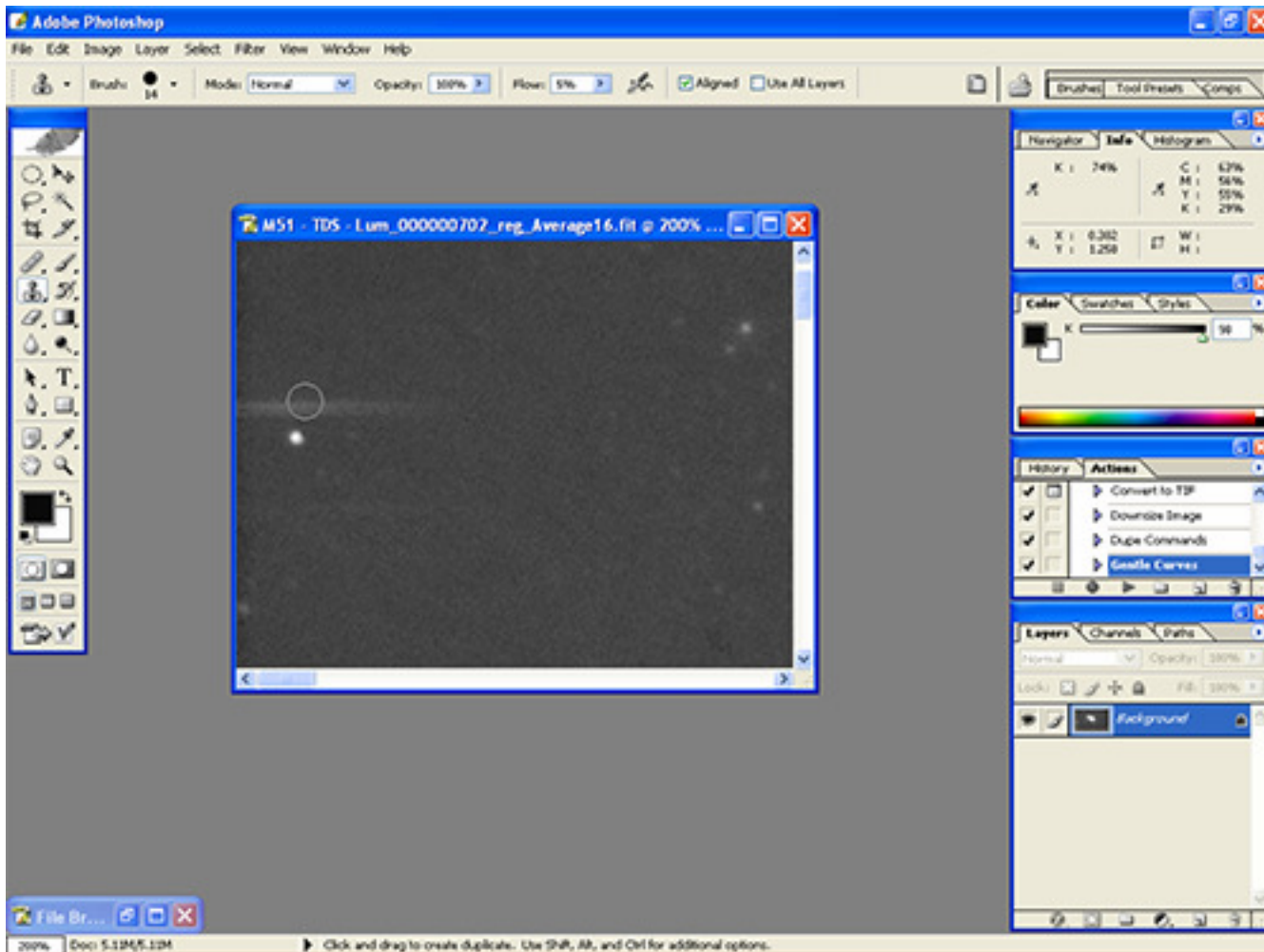


- ▶ Those pesky reflections off our the adaptive optics unit have got to GO!



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The clone tool is an excellent way to “erase away” errors and flaws in our images, particularly in areas free of stars and other data

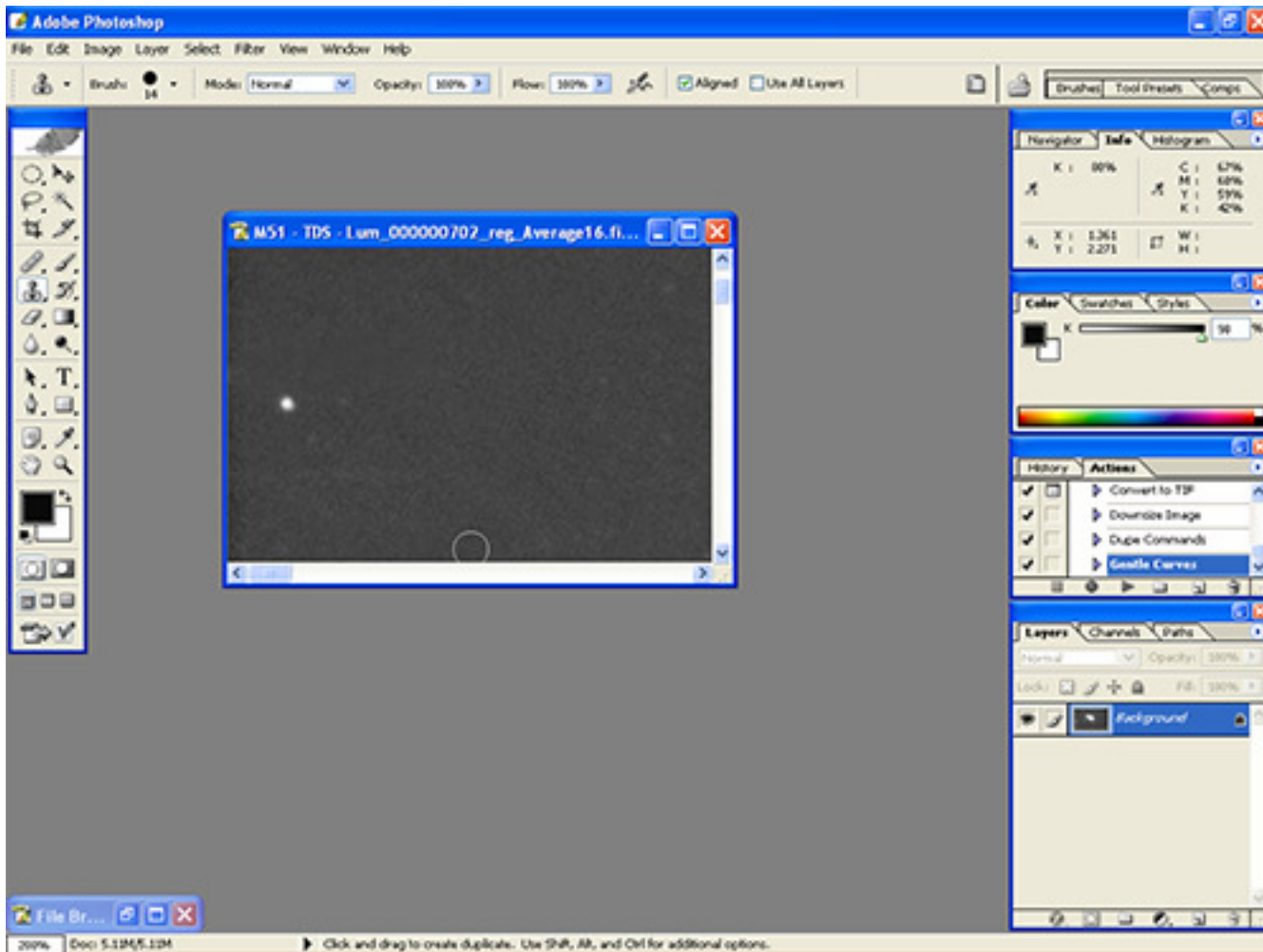


- ▶ We set our brush diameter to a reasonable size for the portion of the image we will be working on
- ▶ We set the brush softness to around 50% to avoid hard edges on our strokes
- ▶ We modify the flow setting to 5% to make all strokes very light and not show any brightness deviations too clearly
- ▶ We select a source very near our area to be corrected and gradually “brush away” the flaw



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The result is an image that is free of the optical flaws, albeit with the loss of a tiny portion of image data



- The clone tool is very tricky to use in areas of the image where you have strong signal

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At this point in our simple processing workflow we have processes a single group of images into a master luminance frame...



Night Sky Photography by Jeff Lunglhofer

Overview

- ▶ Equipment Overview
- ▶ Software/Hardware
- ▶ Image Processing Basics
 - Calibration
 - Selection
 - Alignment
 - Stacking
 - Levels/Curves
 - Layer Blending
 - **Assembling an RGB Image**

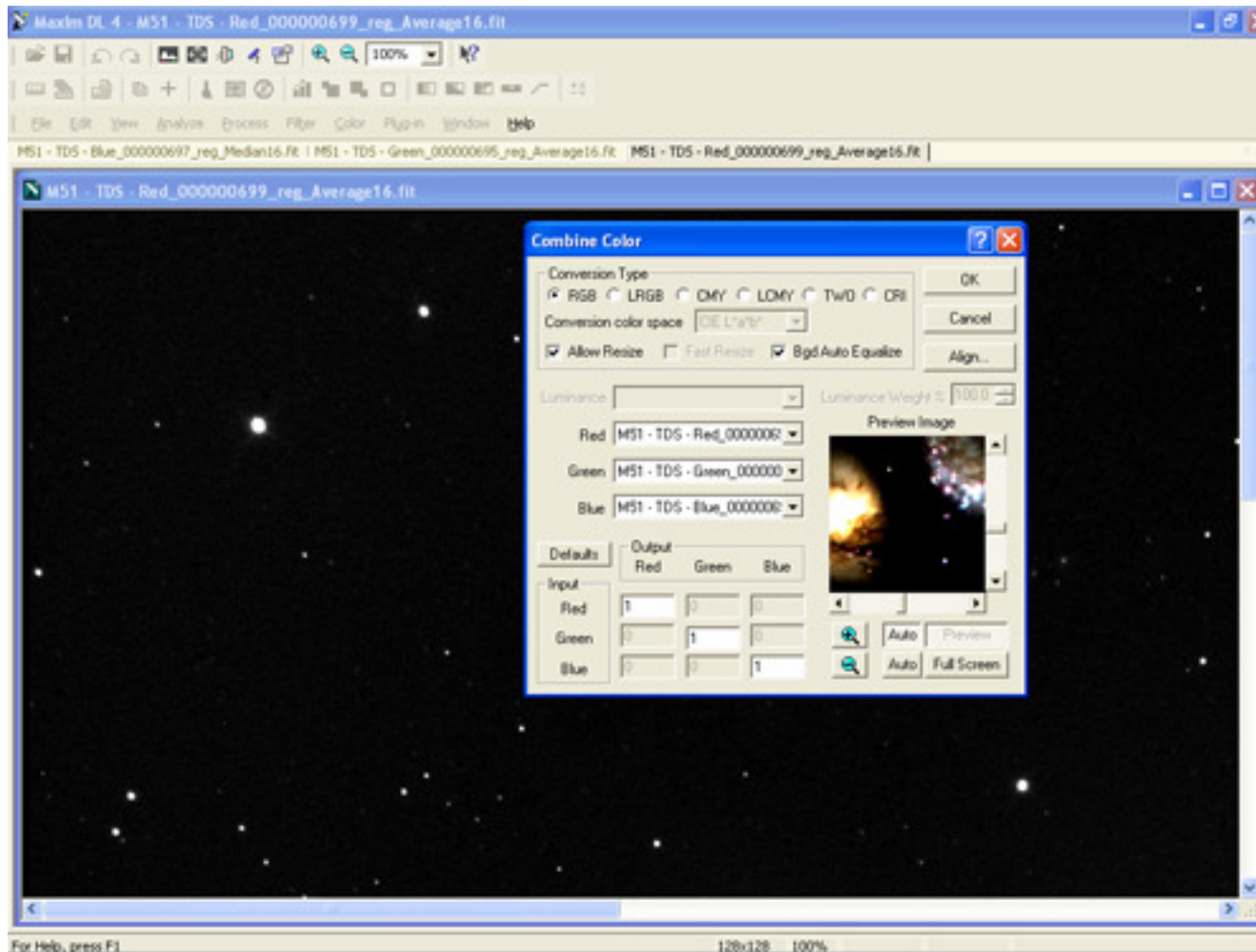


After you have processed your master luminance frame, it's time to assemble the Red, Green, and Blue frames for an LRGB image

- ▶ Color frames are reduced, repaired, aligned, and stacked in exactly the same way as our luminance frame...BUT we do not process individual RGB frames, they will be processed after being combined into a single RGB image
- ▶ Individual Master Red, Green, and Blue frames can be combined via a number of software packages, such as MaximDL, CCDSoft and in Photoshop
- ▶ My preference is MaximDL due to the feature of autobalancing the background to a uniform black, but Photoshop can also work just as well, albeit with a bit more work
- ▶ This section will demonstrate using both to assemble a master RGB stack



MaximDL makes the process of creating an RGB image very straightforward



- ▶ Open your master Red, Green, and Blue images
- ▶ Open up the “Color Combine” dialog and adjust the settings to your preference
- ▶ I always use the “Bgd Auto Equalize” feature
- ▶ You can adjust the weights of the various colors depending upon sensitivity variations in your camera, or other factors. Experimentation is the only way to see what you prefer!
- ▶ You can also identify and photograph a G2V star (similar to the sun) and adjust the weights until the result is a pure white colored star, then use those for “natural” color
- ▶ Save your color stack as a .TIF file so you can process it in Photoshop



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Open up the newly created color .tif file in Photoshop and walk through the usual curves/levels/layer blending process

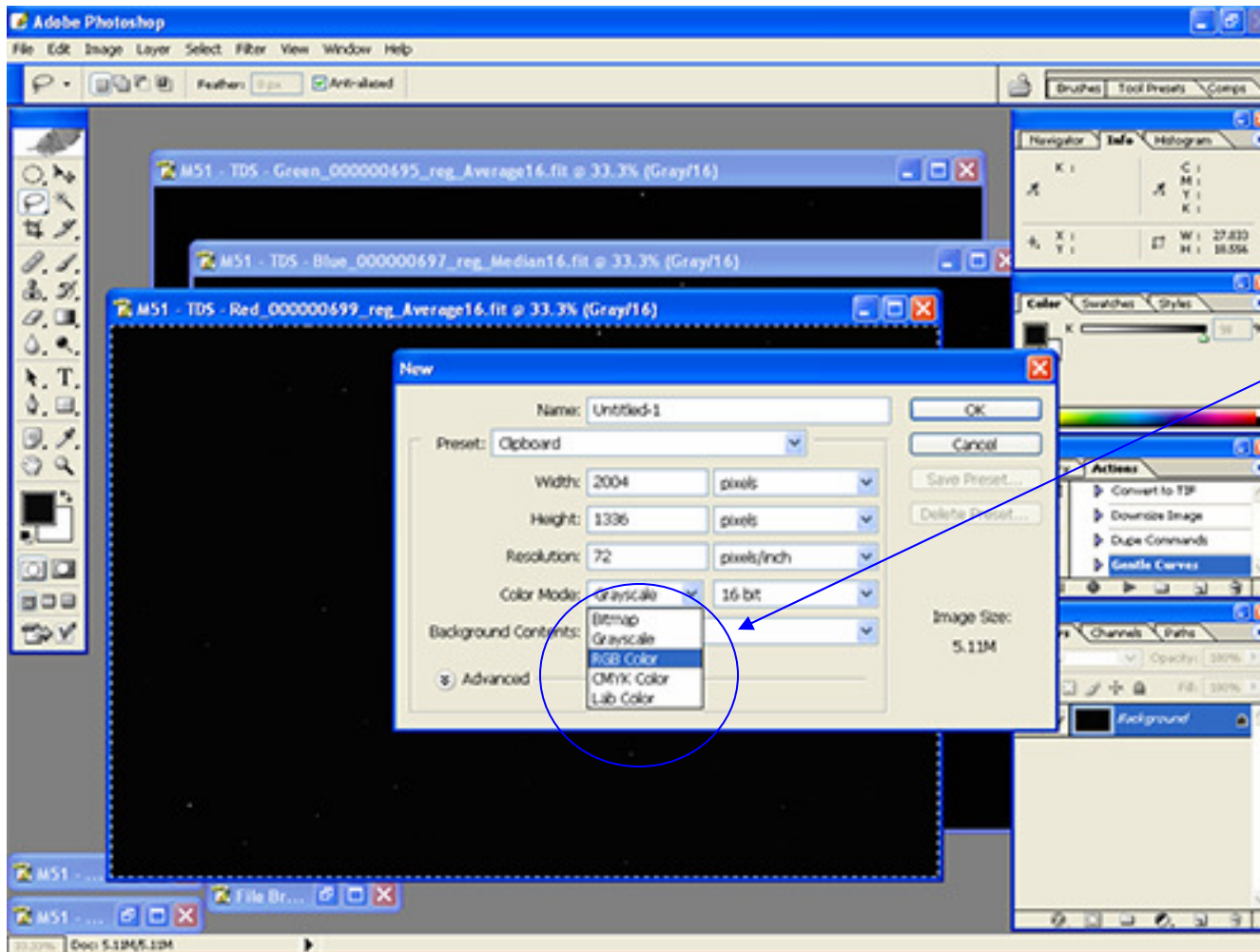


- ▶ This is an image that has been roughly processed with just levels and curves.
- ▶ No other processing has been applied to this image



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It is also possible to create an RGB stack in Photoshop

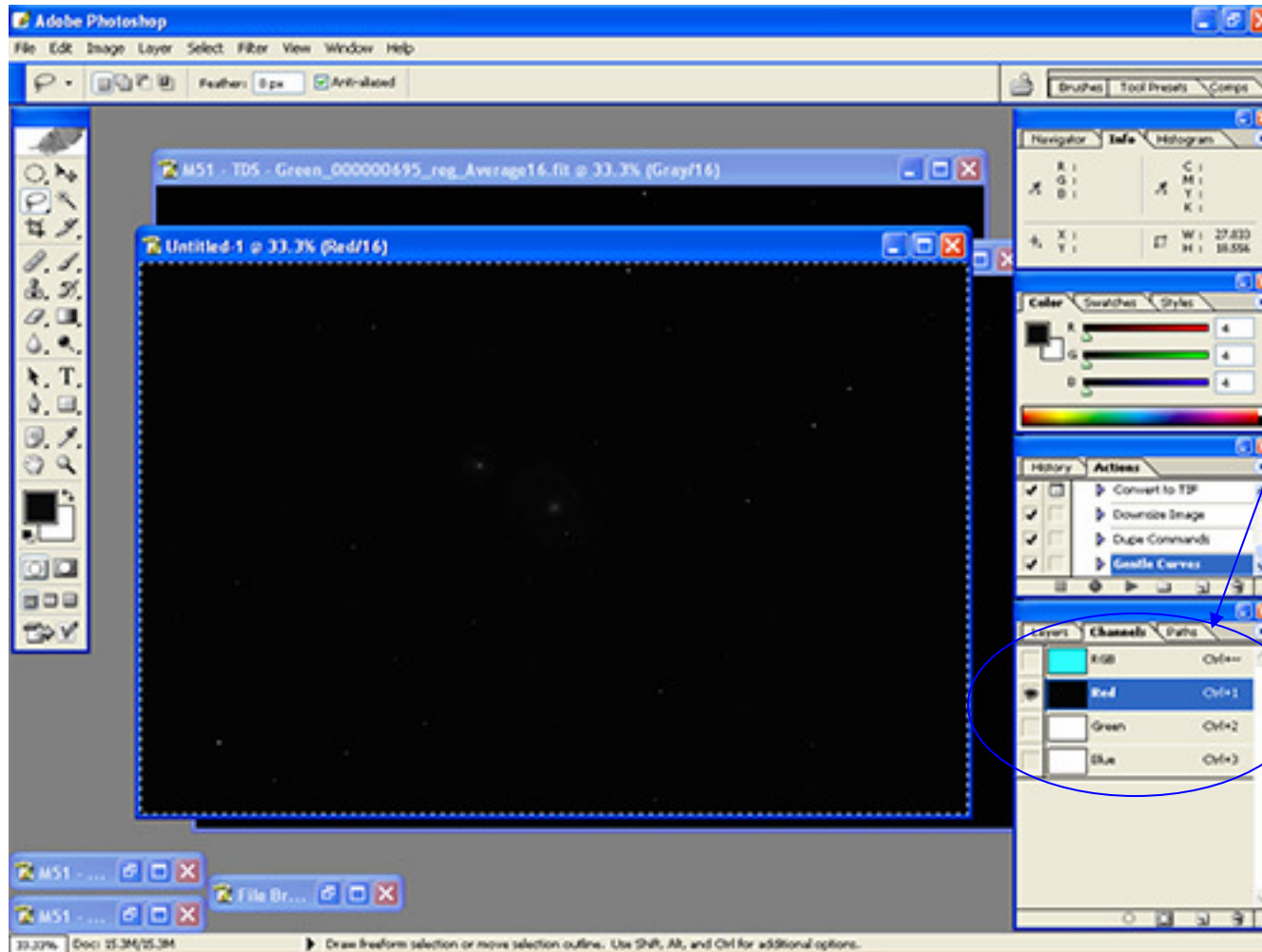


- ▶ First open up all of your master Red, Green, Blue images
- ▶ Copy one of your files to the clip board
- ▶ Create a new file (it will automatically use the image size of the current image in the clip board) and specify that you want an RGB image.



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Next we paste in our individual color files into their appropriate channels

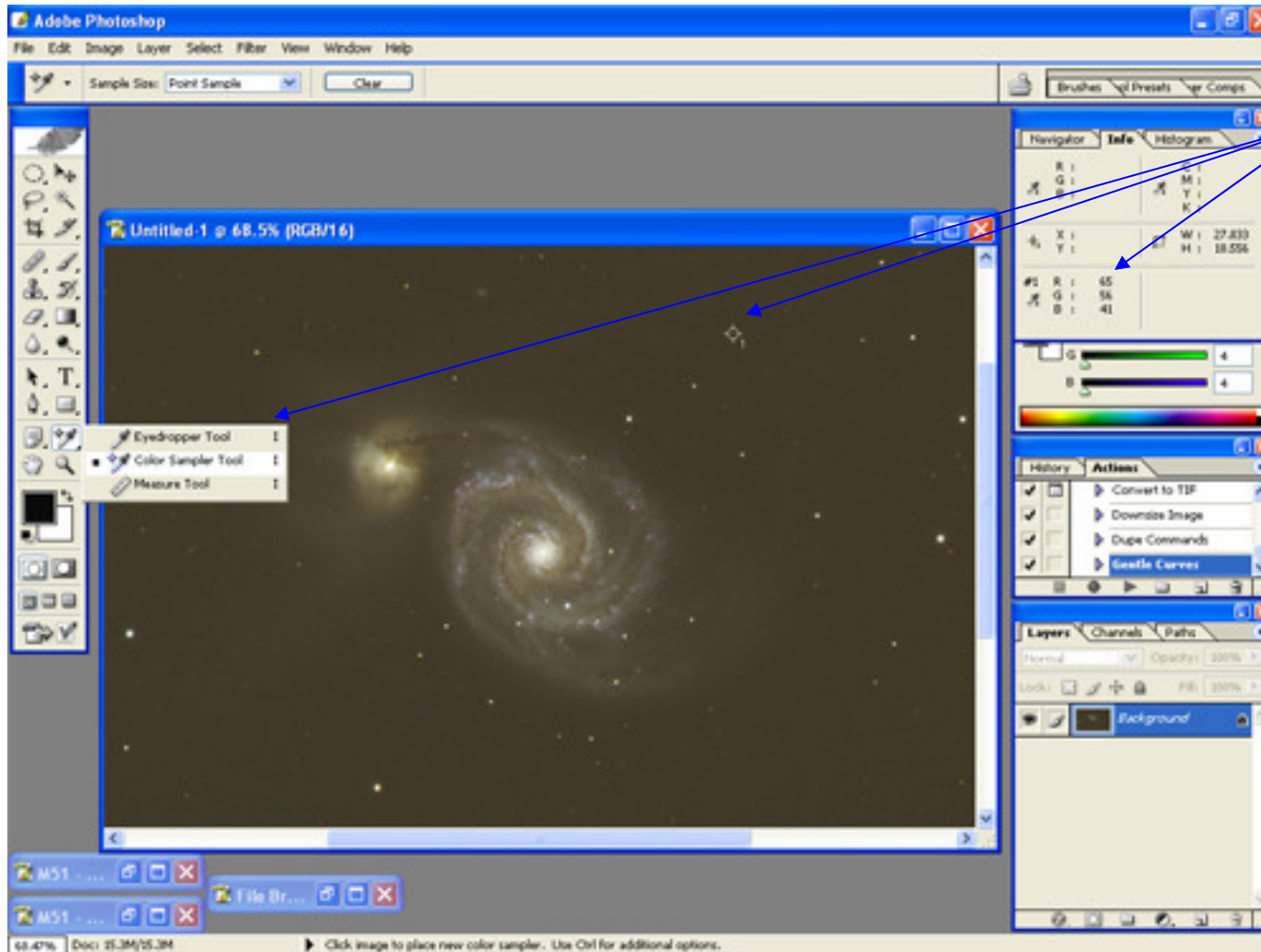


► Paste in each of the color frames into the appropriate channel. Note that this is NOT a normal layer, but goes directly into the channel



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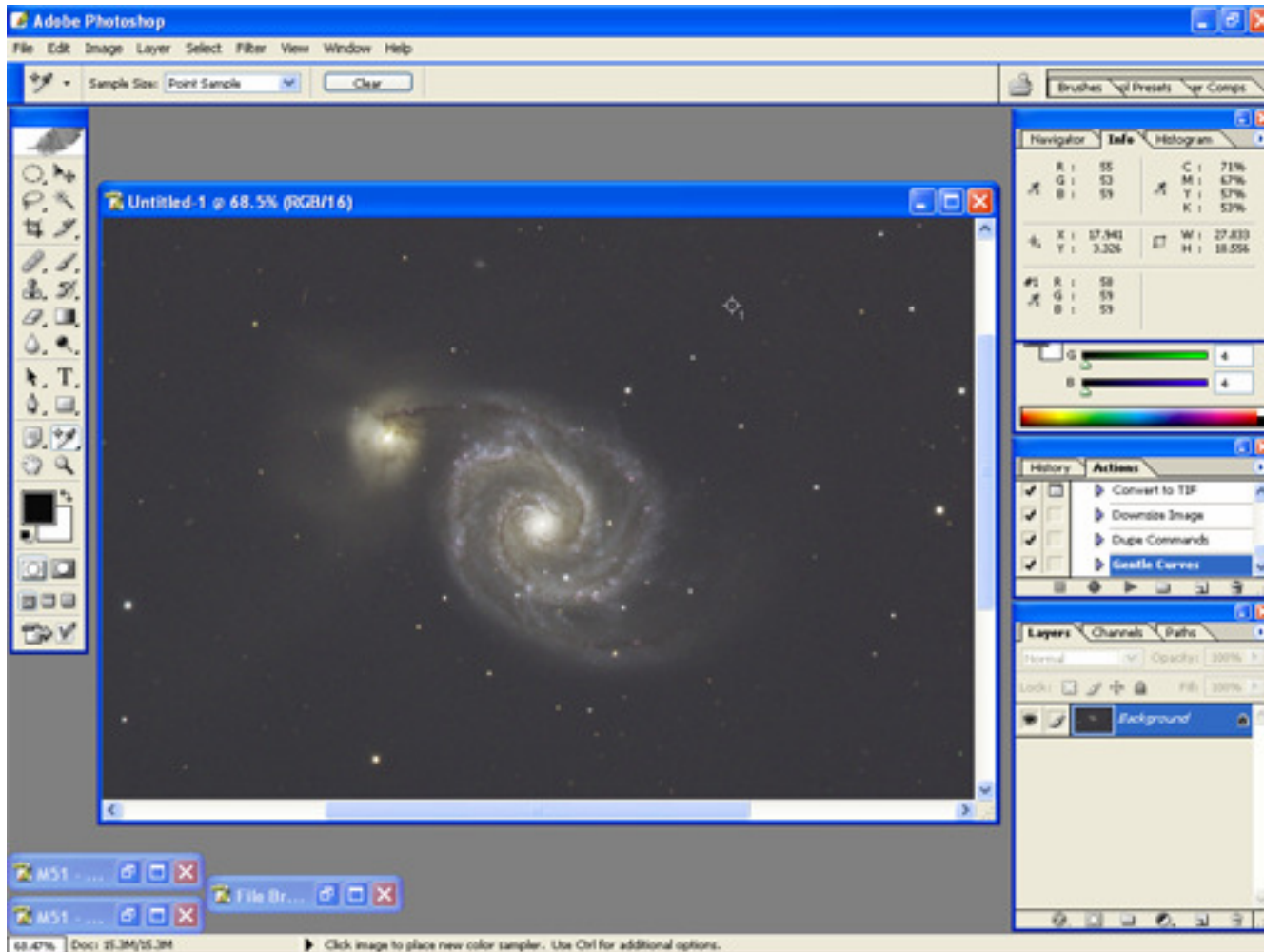
The result is a complete color image, but without background leveling



- ▶ The background is clearly red/green which we can confirm by taking a color sample of the image
- ▶ This image sample taken is a 5x5 pixel average and indicates the following values
 - Red: 65
 - Green: 56
 - Blue: 41
- ▶ This confirms our initial impression that the background is a bit reddish and greenish
- ▶ We will use the curves or level tool (we will have to experiment) to level the background

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After leveling the background we have an full color image that is very similar to the one created with MaximDL

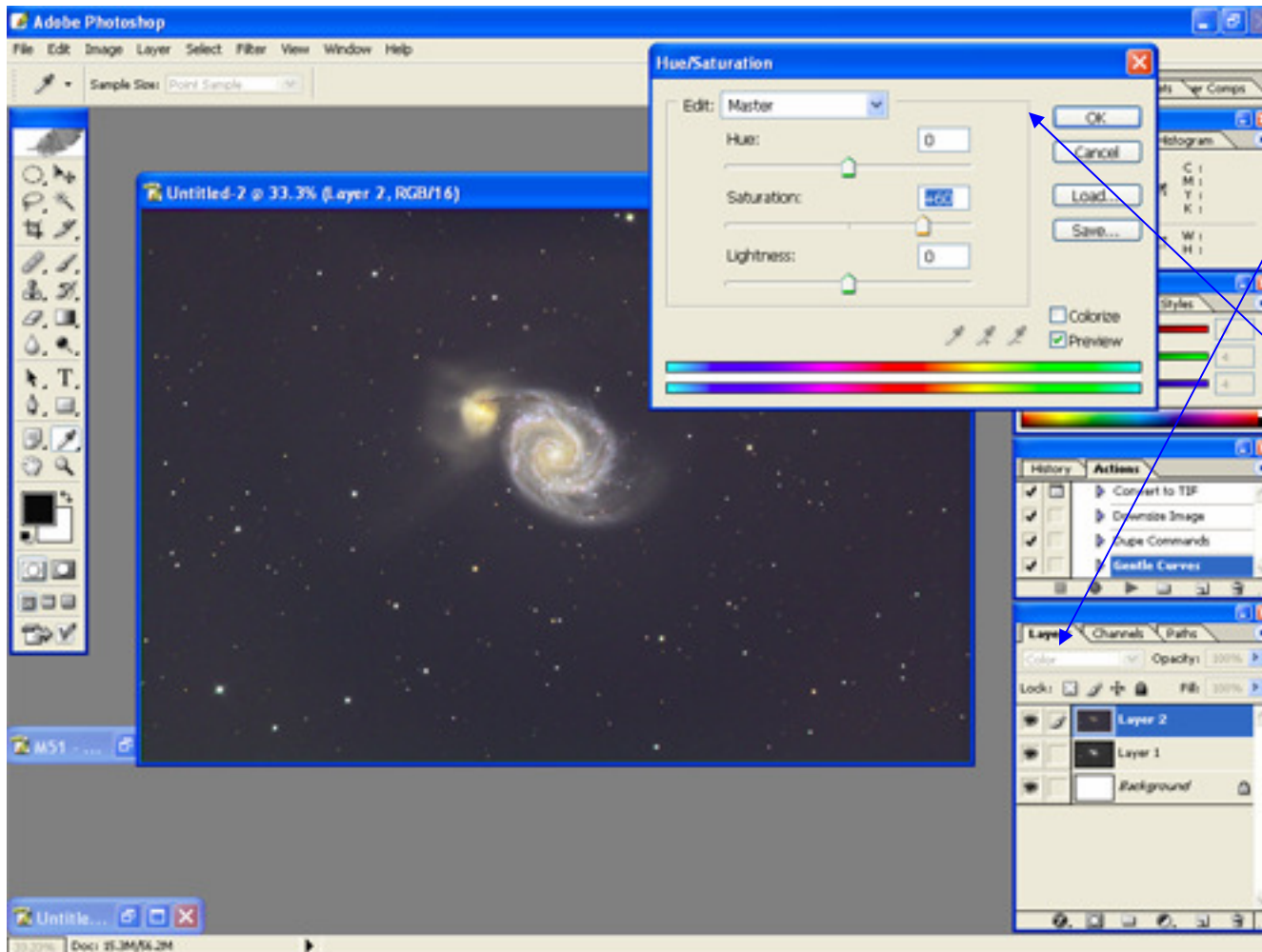


- ▶ The image sample now indicates the following values:
 - Red: 58
 - Green: 59
 - Blue: 59
- ▶ The resulting color image to me look nicer than the one I just created in MaximDL
- ▶ This highlights to me the importance of trying different programs and techniques
- ▶ Getting stuck in a rut of always doing everything the same way will limit your horizons and you'll miss great new techniques!
- ▶ Different images have different needs!



Night Sky Photography by Jeff Lunglhofer

Next we create a new RGB image and layer in first our luminance frame, then our new RGB frame



- ▶ The RGB layer is on top and set as a “color” layer in the layer toolbox
- ▶ Often the color is drowned by the strength of the luminance frame resulting in extremely muted colors
- ▶ Don’t hesitate to play with the saturation level of the color layer to enhance the colors to a satisfactory level
- ▶ Don’t overdo it with saturation!



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Our final image is a product of a lot of hard work, using only the best elements of a range of individual images



- ▶ I finished this image by use a layer to blend in a little more blue into the spiral arms of the galaxy (I have an unhealthy love of blue in my galaxies)
- ▶ I cropped the image to get the viewer a bit closer to the target object, in this case M51
- ▶ I also applied a mild unsharp mask to the high signal portions of the image
- ▶ This is a very simple processing workflow and neglects the dim nebulous areas surrounding this pair...there's a lot more data here we could work with!



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