Composing advanced LRGB images in false colors and creating wide-field mosaics

David Lindemann

Composing advanced LRGB images in false colors and creating wide-field mosaics

Introduction, highlight and summary

CEDIC

- My favorite subjects are mainly emissions nebulae that populate our Milky Way

- My work in astrophotography is characterized firstly by the technical and scientific challenges posed by the capture of deep sky objects and then, for aesthetic sensibility, philosophical and poetic that allow transform them to beautiful and colorful images

- To capture the beauty of these fascinating objects, I use both narrowband and broadband imaging technique

- My aim when I am working on astronomical image, is to stay fully involved and focused on the aesthetic feeling that can emerge during the image processing

- In this workshop I will explain how I use all the following software to create wide-field mosaics and compose LRGB images in false colors :
  - MaximDL 6 for capture and guiding
  - SharpLock 1.0 as an autofocuser
  - SkySurveyor 2.0 to plan and capture mosaic
  - CCDStack 2.76 for calibration, registration and stacking
  - Registar 1.0.7 for mosaic stitching
  - PixInsight 1.8 for mosaic stitching and post processing
  - PhotoShop CE for post processing

Composing advanced LRGB images in false colors and creating wide-field mosaics

Introduction, highlight and summary

- I am always been fascinated by the views of large sky areas, especially images with a lot of details that use pleasing color palettes and offers very aesthetic feeling
- In order to build such images I have developed my astronomical skills in doing large scale mosaic
- Doing a mosaic with a lot of details requires accurate high focal length instrumentations and a lot of time and efforts to achieve all the necessary steps
- According to the weather conditions a wide field mosaic project requires several months to several years to complete

- When starting a mosaic project we must be aware of the following rules and constraints:
  - The higher is the focal length, the smaller is the field of view
  - The smaller is the field of view, the higher is the number of tiles
  - The smaller is the sensor size, the smaller is the field of view
  - The bigger is the sensor size, the higher is the required quality of the lens and the cost of the camera
  - The higher is the focal length, the better will be the resolution of structural details
  - The higher is the focal length, the bigger is the impact of the weather conditions
  - The higher is the number of tiles, the harder is the work to make a seamless image
- The above rules teach us that there is no trivial solution; there is no way to cheat
- We will never get a highly detailed image with short focal length instrument and a minimum of time and efforts
- All engineers knows that to get an optimal solution the only way is to reach a subtle equilibrium between all physical aspects and constraints of a given system

Composing advanced LRGB images in false colors and creating wide-field mosaics

Introduction, highlight and summary

CEDIC

- The expected result will never be perfect, but it can be as close as possible to the optimum that can be reached with available instrumentations, the allocated time and the deal of efforts

- I have developed SkySurveyor to help astrophotographers doing all tasks of such a demanding mosaic project

- SkySurveyor help to:
  - Choose a subject
  - Find right ascension (RA) and declination (DEC) coordinates of a named object from SIMBAD
  - Watch the extent of the subject using several bandwidth among multiple background imagery (Color, H-alpha, Infrared, Ultraviolet, X-ray, Gamma, ...)
  - Define the field of a subject
  - Frame the subject as close as possible interactively on the sky map or by doing small coordinates adjustments
  - Identify the area framed by the sensor as a function of the focal length and the size of the sensor

Composing advanced LRGB images in false colors and creating wide-field mosaics
Introduction, highlight and summary

- SkySurveyor help to (continued):
  - Work with various focal length and sensor size
  - Work with various cameras and filter wheels
  - Work with various telescope mounts
  - Divide the mosaic field into tiles
  - Manage the overlap margin between tiles in order to ensure successful stitching
  - Slant mosaic in order to fit the subject orientation as much as possible
  - Choose the starting point of the mosaic
  - Choose the orientation of the sensor
  - Define how the telescope will move across all tiles of the mosaic
  - Define how many images (subs) that must be captured per tile
  - Define the exposure time of each image
  - Select filters that will be used
  - Give an order to the images to capture
  - Use guider and define guide star exposure time per tile
  - Check how close is the moon from the fields that will be captured to minimize light gradient

Composing advanced LRGB images in false colors and creating wide-field mosaics

Introduction, highlight and summary

At the frontier between art and science

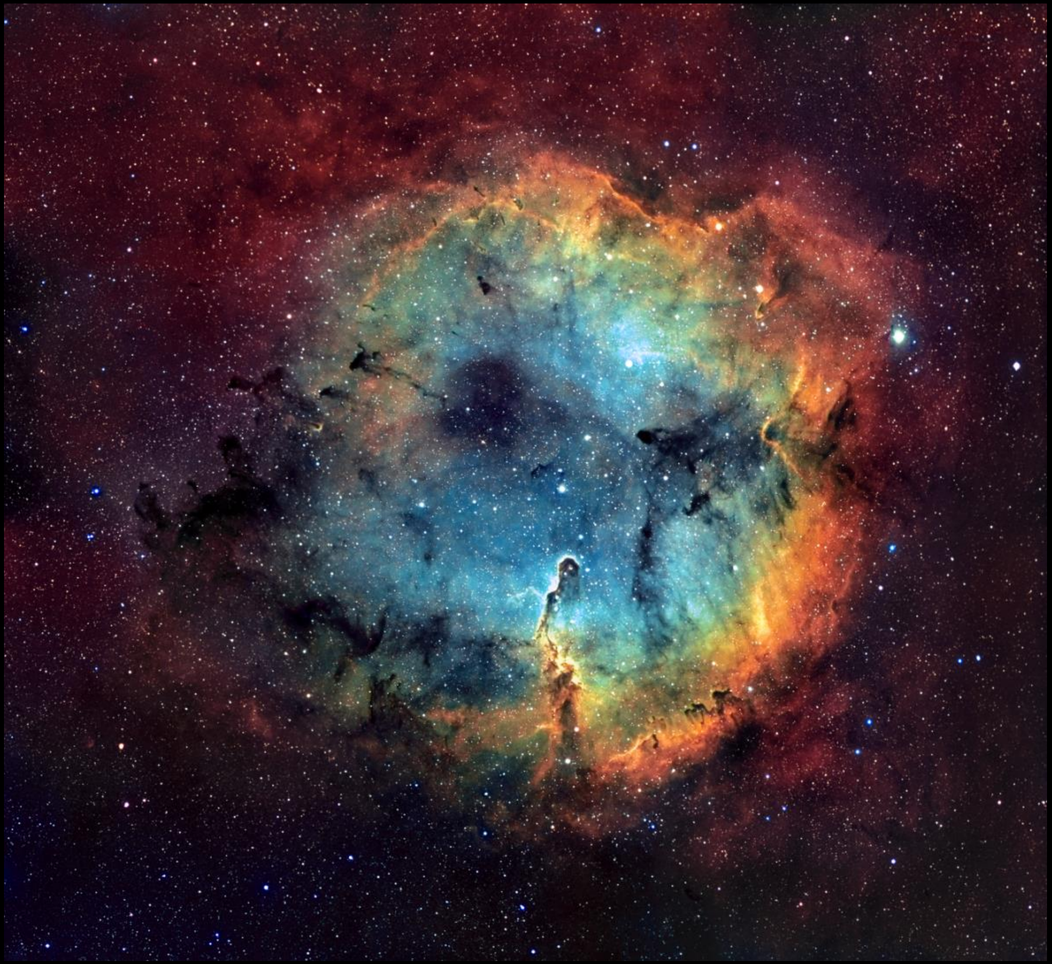
THE IMPRESSIONIST PAINTERS OF THE 19TH-CENTURY ARE ABLE TO CATCH THE FEELING PROVIDED BY NATURAL PHENOMENON IN A VERY AESTHETIC RENDERING AND VERY IMPRESSIVE COLOR PALETTE

IN MY PRACTICE OF ASTROPHOTOGRAPHY I LET MYSELF BE DIRECTED BY THE AESTHETIC FEELING AND BY THE CHROMATIC RANGE GIVEN BY THE HUBBLE PALETTE TO MAKE IMPRESSIONIST ASTROPHOTOGRAPHY

Joseph Mallord William Turner
The Burning of the House of Lords and Commons, 16th October 1834
© Philadelphia Museum of Art

The Burning California, 8 pannels mosaic,
September 2013 - October 2014
© David Lindemann

- This workshop is divided in 216 slides organized in 12 chapters :
  - Chapter 1: Rising of a mosaic project
  - Chapter 2: Sensor alignment
  - Chapter 3: Data acquisition
  - Chapter 4: Preprocessing (Calibration)
  - Chapter 5: Data quality evaluation
  - Chapter 6: Registration (Alignment)
  - Chapter 7: Data rejection and stacking
  - Chapter 8: Mosaic stitching
  - Chapter 9: Creating luminance master frame
  - Chapter 10: Bringing out the structural details
  - Chapter 11: Creating chrominance master frame
  - Chapter 12: Blending luminance with chrominance



Elephant's Trunk nebula (9 panels mosaic)

Chapter 1: Rising of a mosaic project

Creating wide-field mosaics
Rising of a mosaic project

- Rising of a mosaic project seems trivial at the beginning but this is much more complex that what one can imagine

- The first step consists in the selection of a subject
  - What are the coordinates of the subject?
  - How big is the subject?
  - How far goes the extent of the subject?
  - What kinds of objects are visible in the field of the mosaic?

    (Galaxies, Star clusters, Emission nebulae, Reflection nebulae, ...)

- The second step consists of how much the image should be deep and how the mosaic will be captured
  - What is the weaker signal we want to see in the final image? (usually the extensions)
  - What is the nature of the light emitted or reflected by the objects? (narrowband or broadband)
  - What kind of instrumentations (focal length and sensors) we can use for capturing?
  - How to identify the area framed by the sensor as a function of the focal length and the size of the sensor?

Creating wide-field mosaics
Rising of a mosaic project

- How many tiles are required to complete the mosaic?
- How is the orientation of the subject?
- How to find what is the best orientation for the sensors?
- How to move the telescope from tile to tile to avoid leaving holes?
- How long must be the exposure time of a single subframe?
- How many single subframe are required to get a good signal to noise ratio?
- Choose the starting point of the mosaic and how the capture process will progress?
- How many nights are required to capture all?
- I can do this project myself or should I make collaboration with other astrophotographers?

- One key step when starting a mosaic project is to precisely identify the area framed by the available instrumentations. This area is called the Field Of View (FOV)

- The FOV is very important to be able to calculate the center coordinates and the total number of tiles required to entirely frame the subject

Creating wide-field mosaics

Rising of a mosaic project

- Without a software able to manage mosaic and to do this calculation, we must calculate the FOV by using the following maths
- At beginning, the FOV of one pixel must be calcualted by using the following formula:

$$\frac{206P}{F} = \text{FOV of one pixel in arcseconds}$$

Where P is the size of pixel in microns and F is the focal length in millimeters

- If the sensor pixel is not square, the pixel FOV must be calculated in both dimensions (height and width)

Creating wide-field mosaics
Rising of a mosaic project

- To calculate the FOV of the whole sensor the FOV of a pixel must be multiplied by the number of pixels in both dimensions (height and width)

$$\frac{206P}{F}W = FOV\ of\ the\ sensor\ width\ in\ arcseconds = WFOV$$

Where W is the width of the sensor in number of pixels

$$\frac{206P}{F}H = FOV\ of\ the\ sensor\ height\ in\ arcseconds = HFOV$$

Where H is the height of the sensor in number of pixels

- To get the FOV in degrees, the WFOV and HFOV must be divided by 3600
- The FOV in degrees is required to calculate RA and DEC coordinates of each tile center point and to know the FOV of a tile

Creating wide-field mosaics
Rising of a mosaic project

- To calculate the RA coordinate from degrees to hours the FOV must be divided by 15
  - one hour is equal to 15° (24 hours x 15° = 360°)
- With rectangular sensor this is very important to know its orientation before starting to calculate the coordinates of the center point of each tile
- To ease the calculation I strongly recommend to align the sensor orthogonally on the equatorial grid
- Orthogonal alignment means that both dimensions of the sensor are parallel to the equatorial grid
- With rectangular sensor, two orientations can be chosen:
  - Portrait = longest dimension of the sensor is aligned to be parallel to the DEC axis
  - Landscape = longest dimension of the sensor is aligned to be parallel to the RA axis
- Before calculating the center coordinates of each tile by using the WFOV and HFOV offset, I strongly recommand to subtract an overlap margin that will be necessary to make a good mosaic stitching
- This margin must be large enough (between 12% to 15% of the sensor FOV)

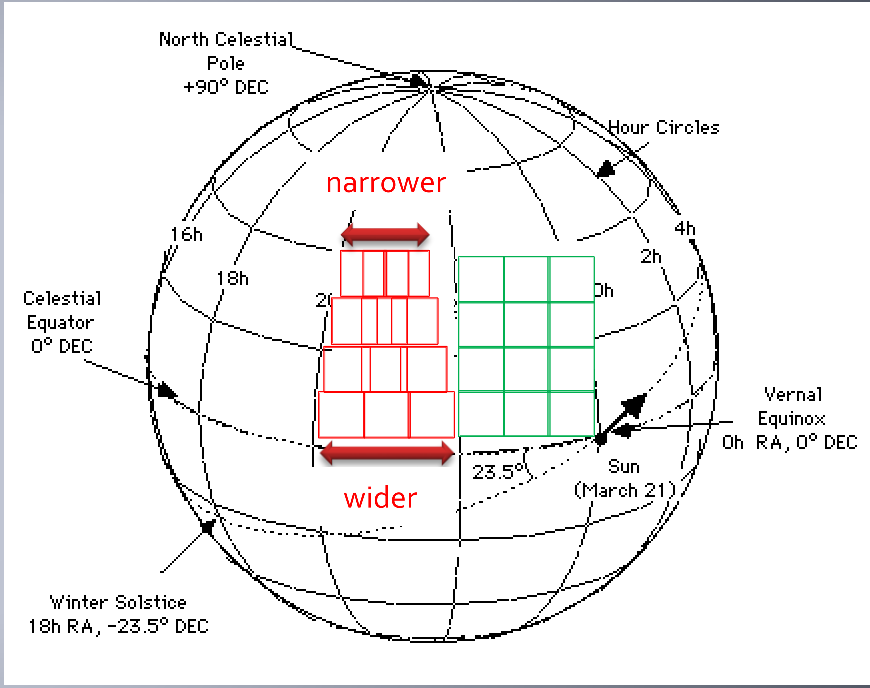
Creating wide-field mosaics

Rising of a mosaic project

- As we use the FOV of the sensor as an offset of the RA coordinate to calculate the center coordinates of the next tile, the offset must be corrected with the declination

- Without correction (see red illustration) the overlap area between tiles increase in direction of celestial pole and decrease in direction of the celestial equator
  - Toward Pole the mosaic become narrower
  - Toward Equator the mosaic become wider

- With correction the overlap area remains constant (see green illustration)



Creating wide-field mosaics

Rising of a mosaic project

- To calculate the RA of center of the next tile and to take in account the declination the following formula is required:

$$\alpha + \left((FOV\alpha - M) \left(\frac{1}{1 \cos\left(\frac{\pi}{180} FOV\delta\right)} \right) \right) = \alpha \text{ of next tile}$$

Where α is the RA coordinate in arcseconds, $FOV\alpha$ is the field of view of the dimension of the sensor that is oriented parallel to the RA axis, M is the overlap margin in arcseconds and $FOV\delta$ is the field of view of the dimension of the sensor that is oriented parallel to the DEC axis

Creating wide-field mosaics
Rising of a mosaic project

- As I mentioned before, the orientation is very important, this avoids wrong coordinates calculation and leaving holes between an image and another

- Without orthogonal alignment a rotation matrix must be applied to calculate the next tile coordinates:

$$\begin{pmatrix} cos\theta & \cdots & -sin\theta \\ \vdots & \ddots & \vdots \\ sin\theta & \cdots & cos\theta \end{pmatrix} = \mathrm{R}$$

Where θ is the angle of the sensor and R is the rotation matrix

- Using a matrix makes the coordinates calculation very complex and the risk of wrong coordinates calculation and leaving holes between tiles is growing dramatically

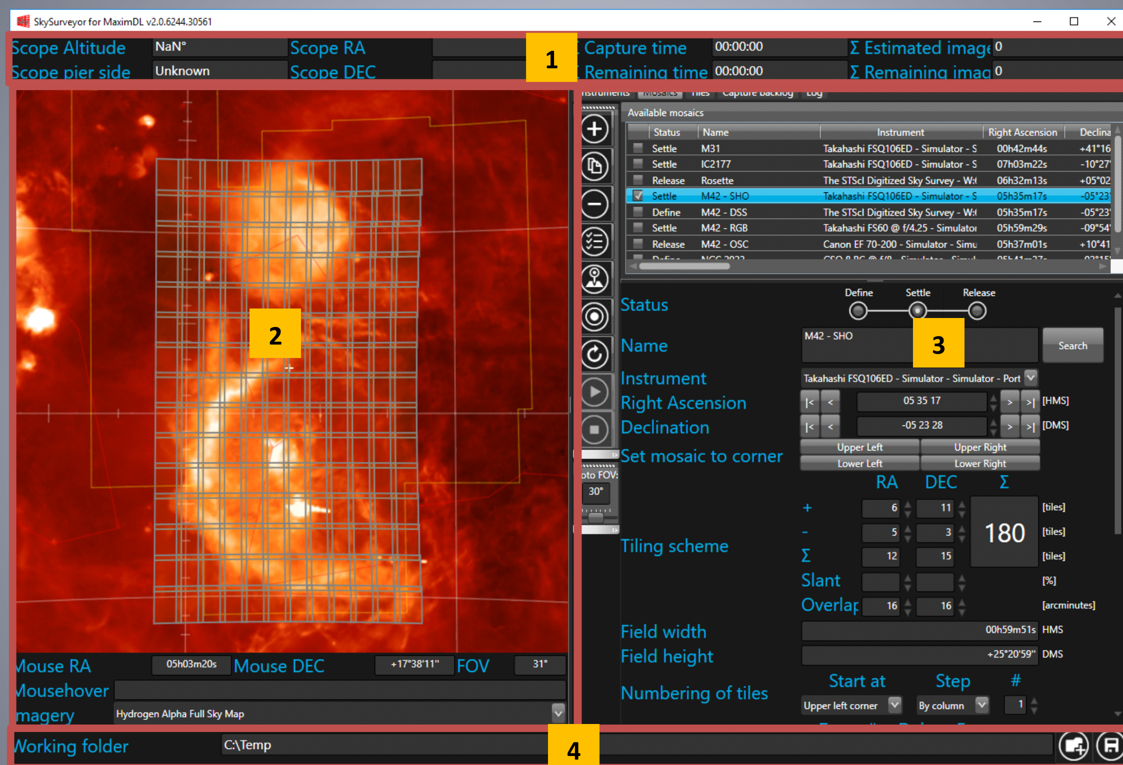
- As we see, this is already not easy for one instrument but the complexity is growing if we plan to use multiple instruments and/or collaborate with other astrophotographers because all that calculations must be repeated for every instrument

Creating wide-field mosaics
Rising of a mosaic project

- SkySurveyor provide a good mean to address all that questions and to deliver us from this complex calculation job
- One of its key features is the WYSIWYG "What You See Is What You Get" user interface that allows the user to view something very similar to the end result while the project is being created
- WYSIWYG implies the ability to directly manipulate the images segments of a project without having to type or remember names of commands and without having to calculate geometric transformation to get the center of each tiles of the mosaic

Creating wide-field mosaics

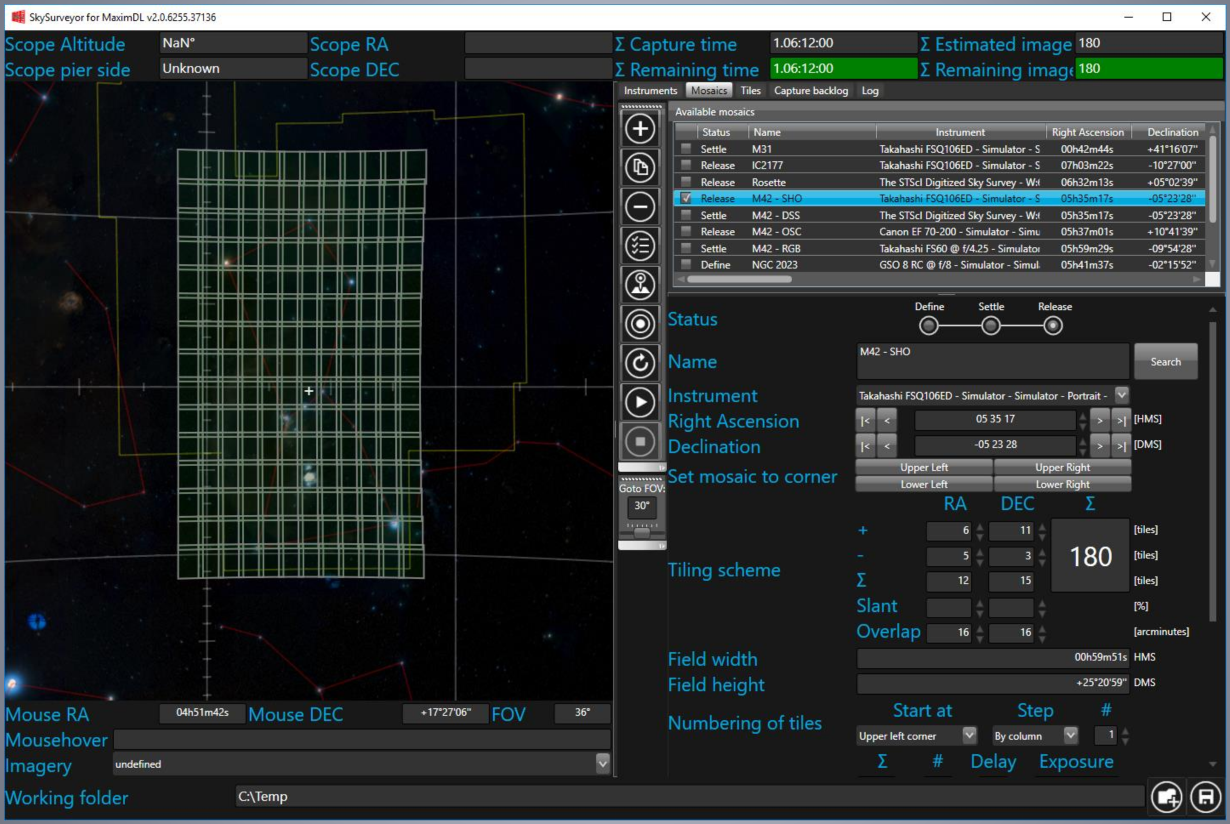
Rising of a mosaic project



- The user interface of SkySurveyor is divided in 4 zones:
  1. The capture indicators (remaining time, number of images, and telescope location, …)
  2. The interactive sky map
  3. The command toolbars, the available object lists and their configuration settings
  4. The working folder and the save command button

Creating wide-field mosaics

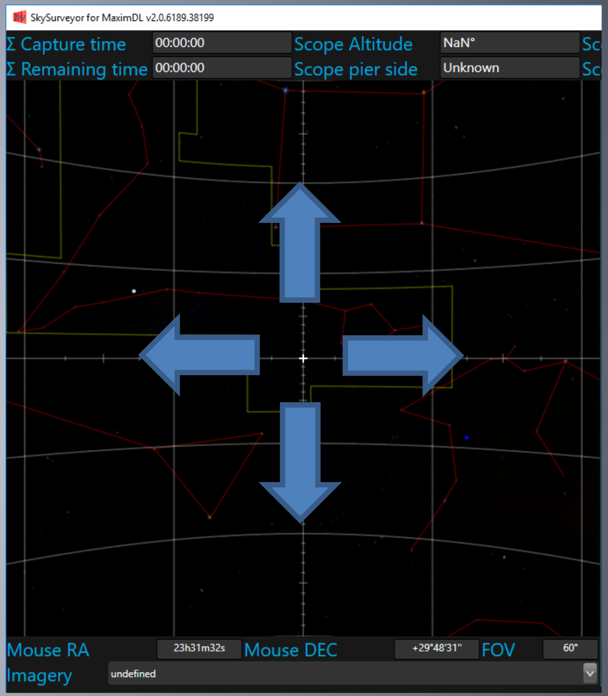
Rising of a mosaic project



- The sky map shows the field of every individual image of one or several mosaic at a time as a graphical overlay drawn above selectable background imagery
- By default the sky map start with the Digitized Sky Survey (color) background

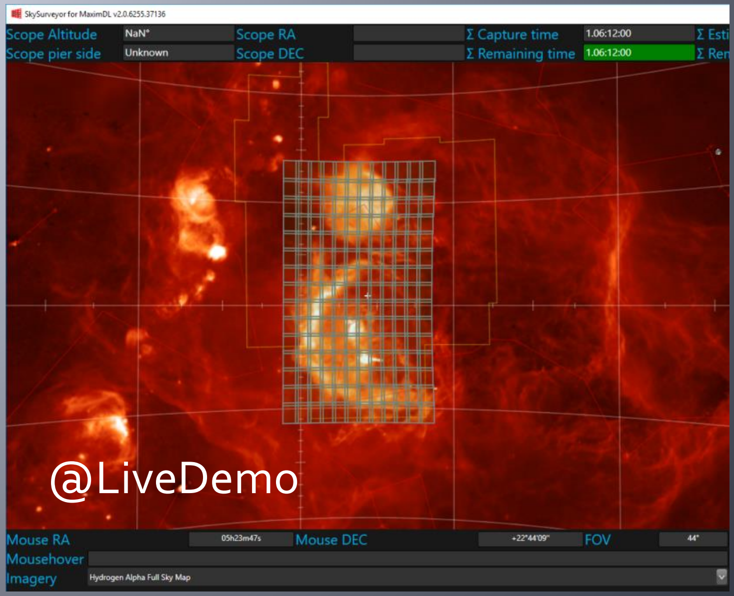
Creating wide-field mosaics
Rising of a mosaic project

- To pan the sky map, just click on the map with the right mouse button and hold the button down while moving the map to the directions indicated by the blue arrows
- To zoom in/out use the mouse wheel
- With a touch screen, pan the map with the finger by a simple touch and swipe
- The RA and DEC coordinates correspond to the location of the mouse cursor on the sky map
- The FOV correspond to the current field of view (range is between 0° and 60°), the FOV changes when zooming



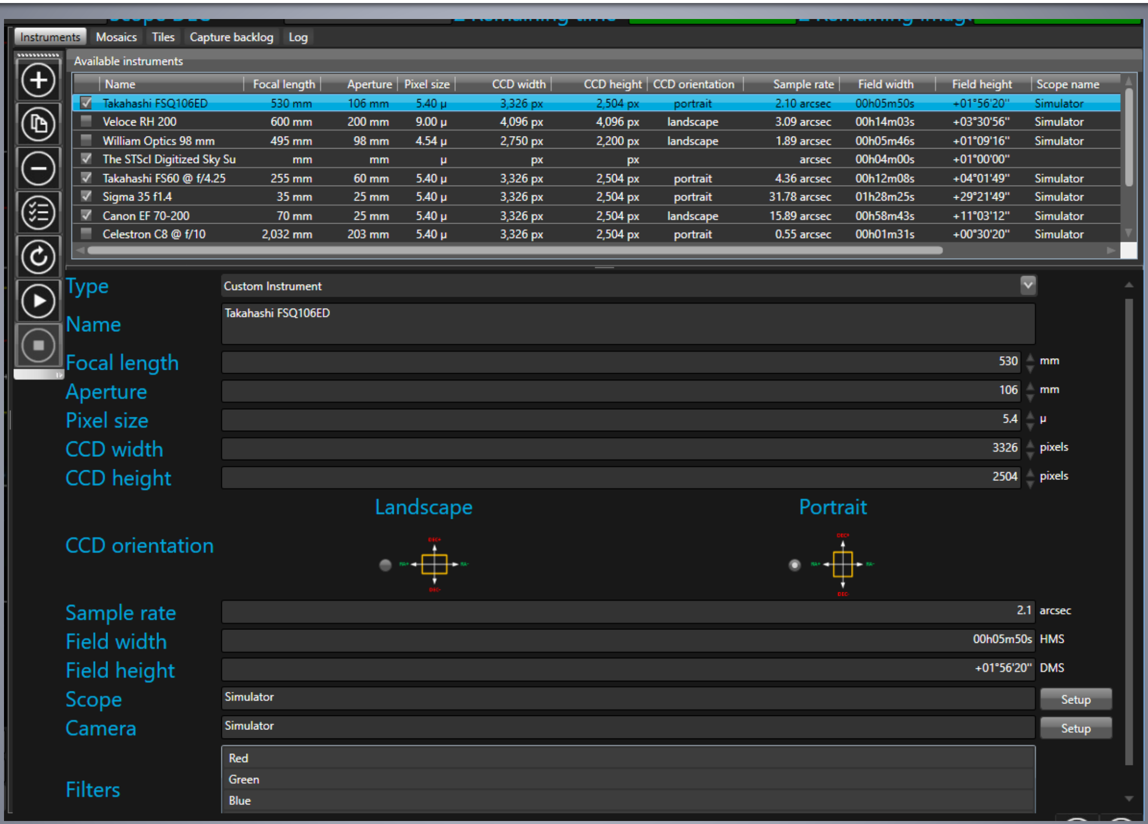
Creating wide-field mosaics
Rising of a mosaic project

- The imagery drop down list allows changing background sky map
- 20 background sky maps in various bandwidths are available
- This bunch of background allows seeing how the project is overlapping the targeted object
- To make an example, we can select "Hydrogen Alpha Full Sky Map" and we can check if all extensions of the targeted object will be correctly framed or not



Creating wide-field mosaics

Rising of a mosaic project

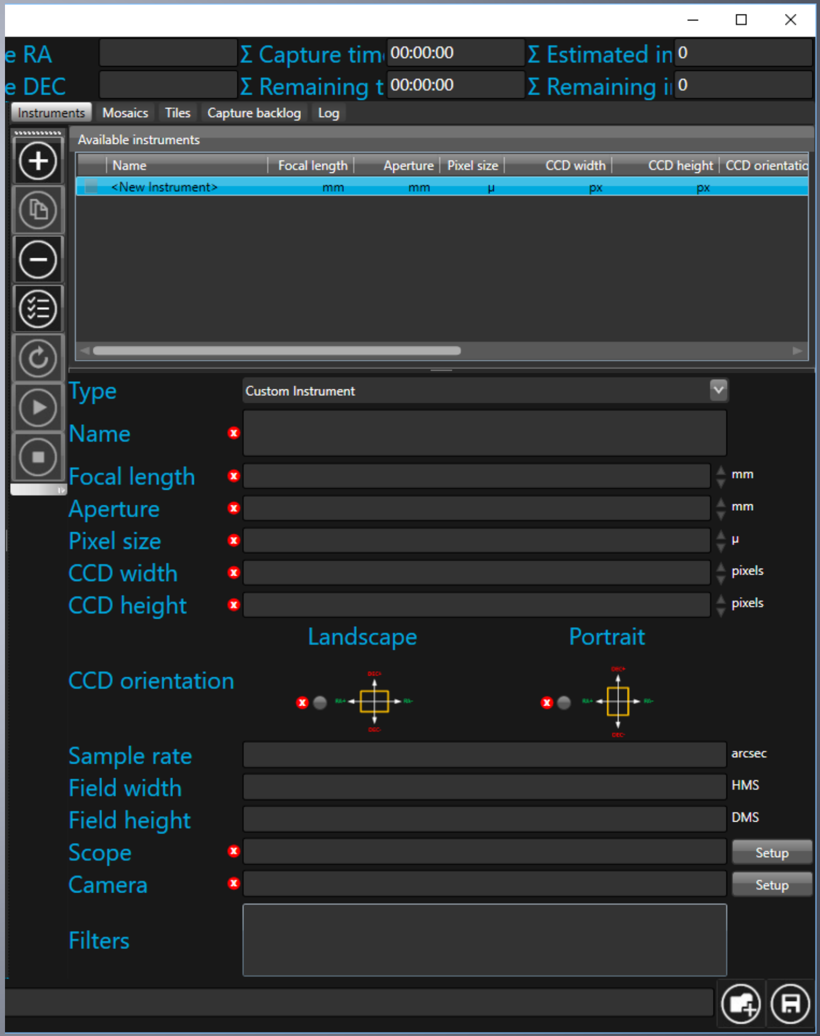


- With SkySurveyor we can configure all the instruments and see the FOV of each one directly on the sky map with graphical overlays
- To configure instruments, simply add them in the available instruments list

Creating wide-field mosaics

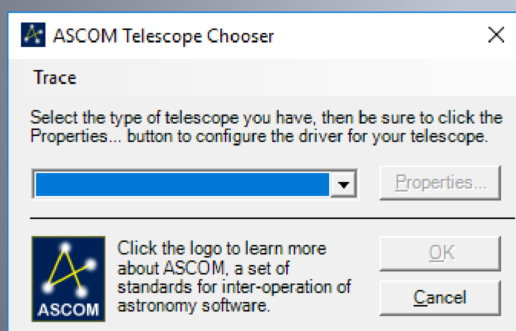
Rising of a mosaic project

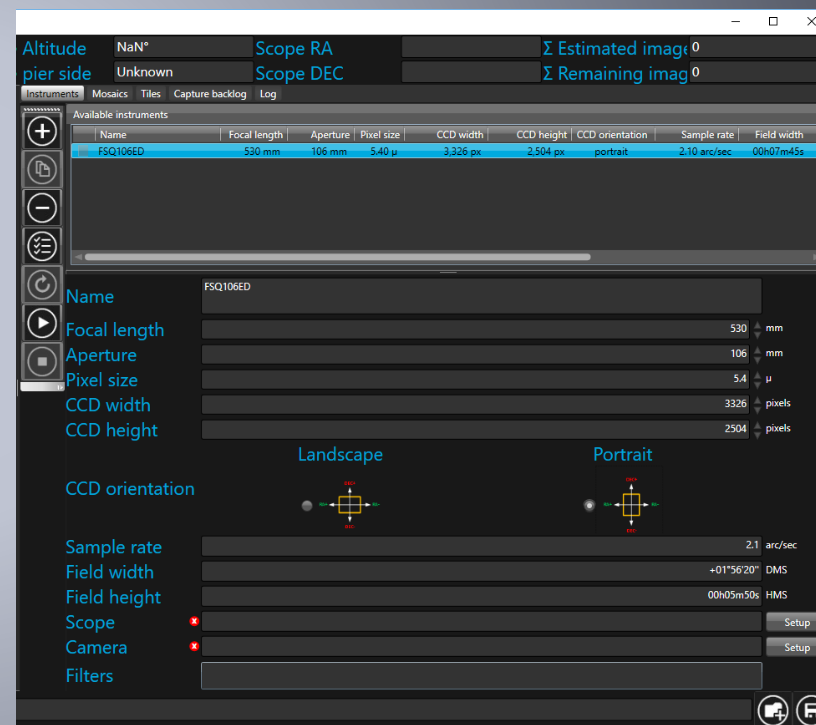
- To add a new instrument click the button
- Once clicked a new instrument is added and selected
- The form that allows editing the instrument settings automatically displays new instrument
- All invalid fields are identified by this icon
- The instrument cannot be used until all fields are valid
- To understand why a field is invalid, just move the mouse cursor on top of the invalid icon and read what is displayed in the tooltip



Creating wide-field mosaics
Rising of a mosaic project

- To configure the telescope mount, click the “Setup” button
- Select the appropriate mount driver in the drop down list of the “ASCOM Telescope Chooser” and click “OK” button to confirm





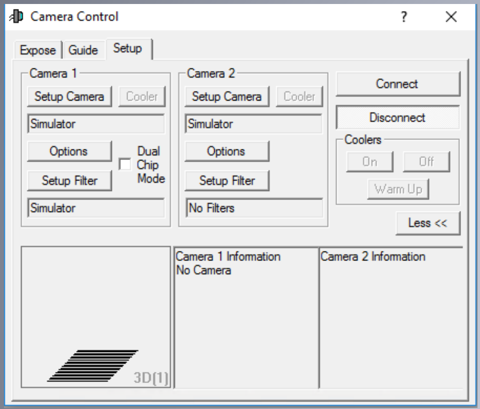
- Once the telescope mount is configured it become valid

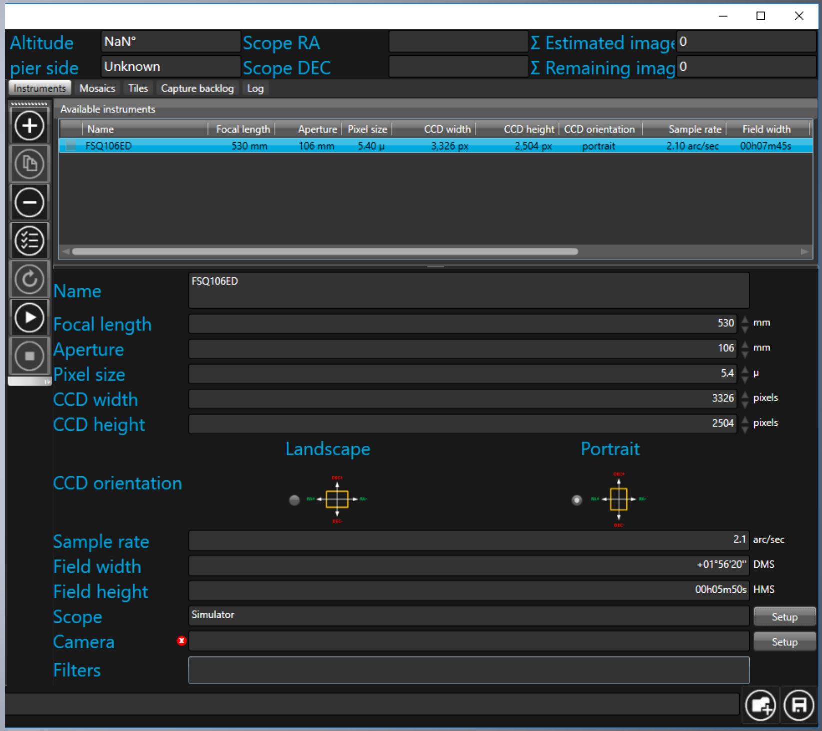
Creating wide-field mosaics

Rising of a mosaic project

CEDIC

- To configure the camera, click the “Setup” button

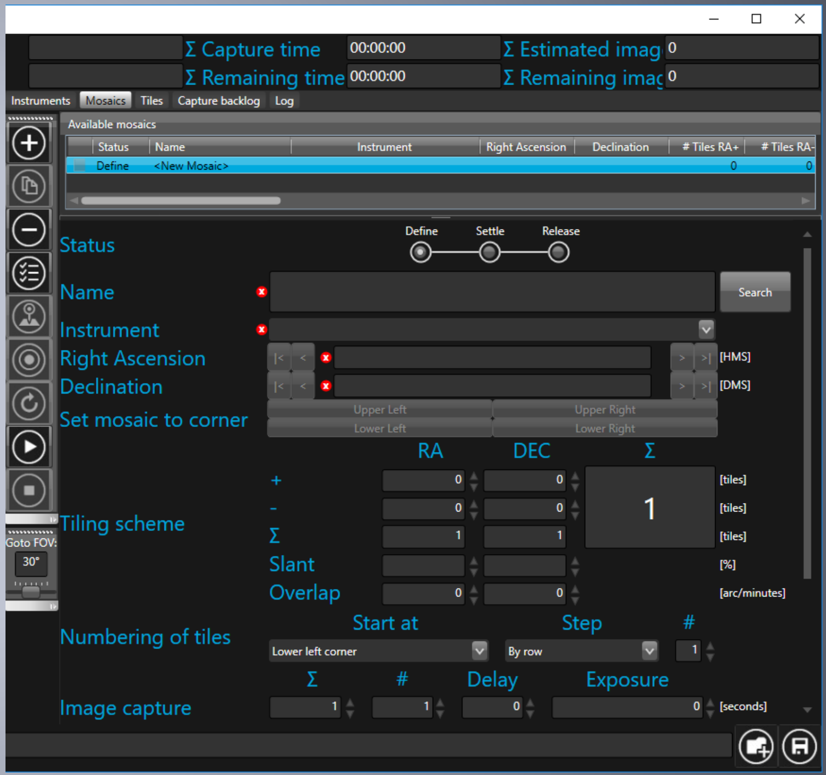




- SkySurveyor automatically load the camera and the filters that have been configured in MaximDL
- Once all fields are correctly filled, the instrument can be used to build a mosaic project

Creating wide-field mosaics
Rising of a mosaic project

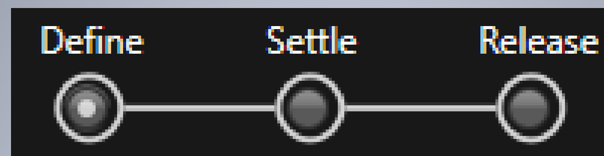
- To add a new mosaic click the button
- Once clicked a new mosaic is added and selected
- The form that allows editing the moasic settings automatically displays the new mosaic
- All invalid fields are identified by this icon
- The instrument cannot be used until all fields are valid
- To understand why a field is invalid, just move the mouse cursor on top of the invalid icon and read what is displayed in the tooltip



Creating wide-field mosaics

Rising of a mosaic project

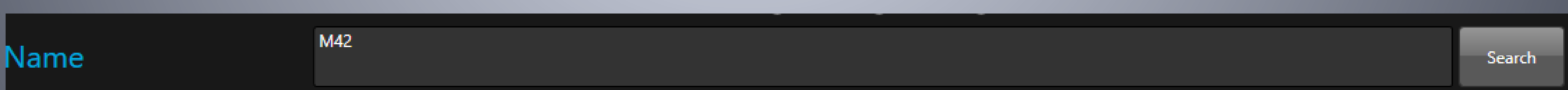
- The mosaic composition is driven by a 3 steps workflow:



  - **Define** the mosaic
  - **Settle** each tiles
  - **Release** the mosaic for capturing

- The mosaic status cannot be set to a higher status than define until all fields are valid

- First enter the name of the object that is the main subject of the mosaic



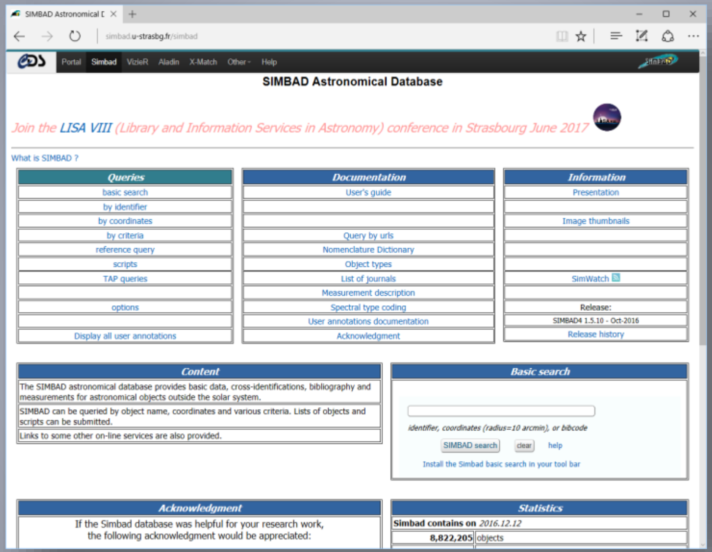
- If the name of the object correspond to a reference in a official catalog (e.g. M42) the object RA and DEC coordinates can be automatically loaded from the SIMBAD Astronomical Database

Creating wide-field mosaics

Rising of a mosaic project

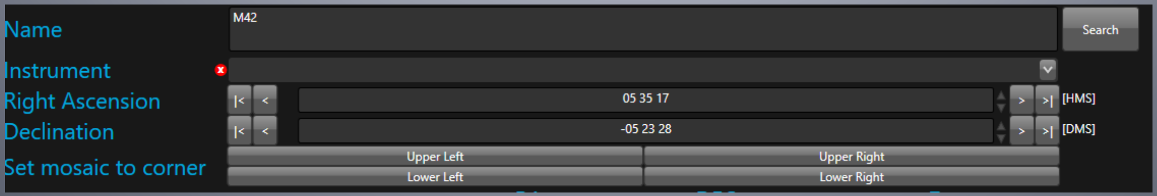
CEDIC

- To get coordinates from SIMBAD, click the Search button



The world database for the identification of astronomical objects

- If the object is referenced in SIMBAD, its RA & DEC coordinates are automatically loaded into the Right Ascension and Declination fields



Creating wide-field mosaics

Rising of a mosaic project

- Select an instrument from the available instruments:

Instrument FSQ106ED - Simulator - Simulator - Portrait - D:106 mm, f:530 mm, f/D:5, W:3326 px, H:2504 p

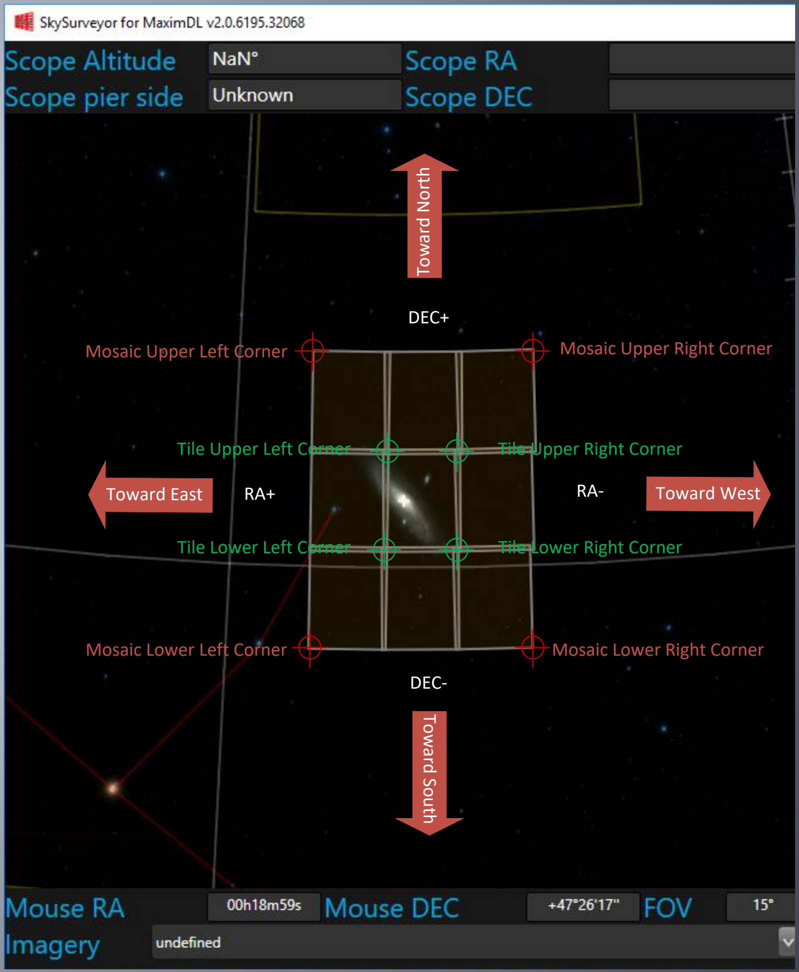
- Takahashi FSQ106ED - Simulator - Simulator - Portrait - D:106 mm, f:530 mm, f/D:5, W:3326 px, H:2504 px, P:5.4 microns
- The STScI Digitized Sky Survey - W:60 arcmin H:60 arcmin
- Takahashi FS60 @ f/4.25 - Simulator - Simulator - Portrait - D:60 mm, f:255 mm, f/D:4, W:3326 px, H:2504 px, P:5.4 microns
- Sigma 35 f1.4 - Simulator - Simulator - Portrait - D:25 mm, f:35 mm, f/D:1, W:3326 px, H:2504 px, P:5.4 microns
- Canon EF 70-200 - Simulator - Simulator - Landscape - D:25 mm, f:70 mm, f/D:2, W:3326 px, H:2504 px, P:5.4 microns
- GSO 8 RC @ f/8 - Simulator - Simulator - Landscape - D:203 mm, f:1624 mm, f/D:8, W:3326 px, H:2504 px, P:5.4 microns

- The next step is to define how the mosaic will be decomposed into tiles
- To do this there are various settings:

		RA	DEC	Σ	
Tiling scheme	+	6	11	180	[tiles]
	-	5	3		[tiles]
	Σ	12	15		[tiles]
	Slant				[%]
	Overlap	16	16		[arcminutes]
Field width		00h59m51s			HMS
Field height		+25°20'59"			DMS

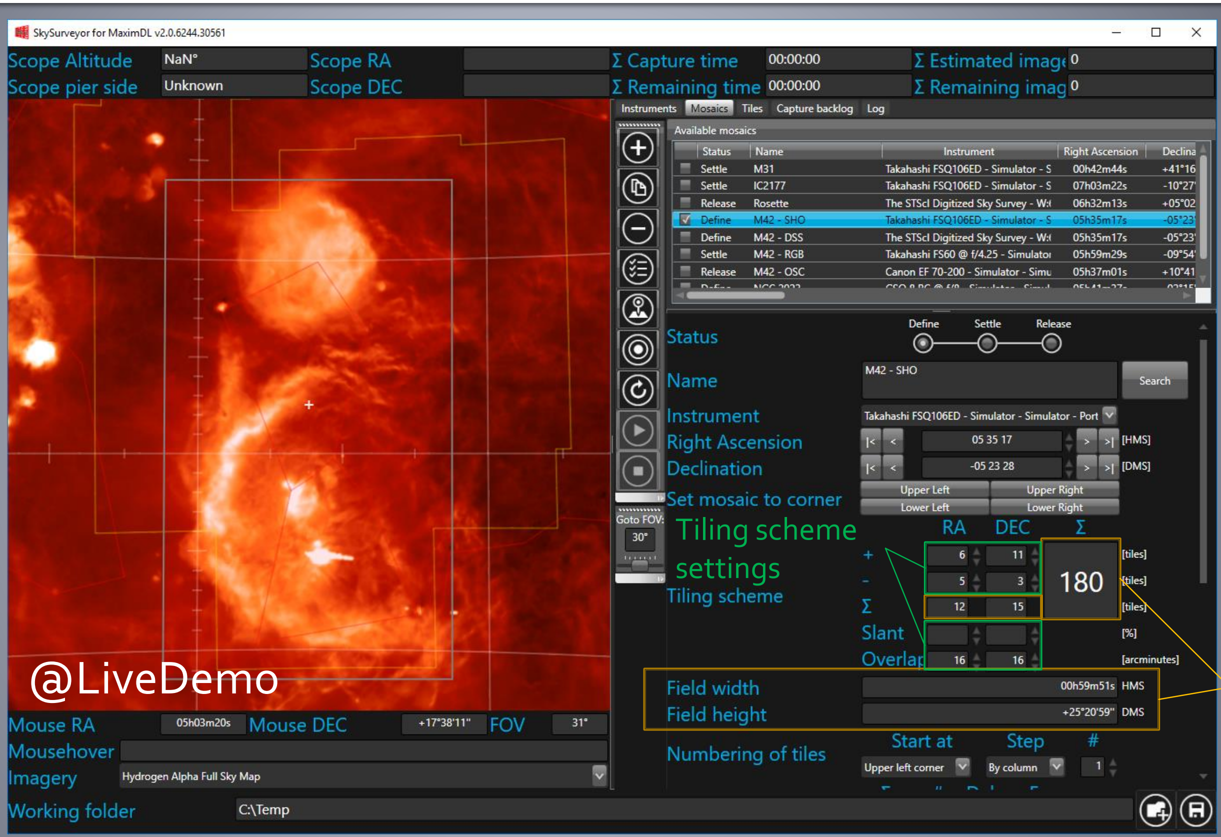
Creating wide-field mosaics
Rising of a mosaic project

- The WYSIWYG user interface allows to easily defining the field of the mosaic by changing the tiling scheme
- Before defining the tiling scheme, its important to understand how the settings control the position and extent of the mosaic field
- The tiling scheme allows controlling …
  - The number of tiles toward the direction of cardinal points
  - The tile overlap margin in both direction (Right Ascension and Declination)
  - The mosaic slant factor in both direction (Right Ascension and Declination)
- To increase / decrease the field of the mosaic toward North the DEC+ must be incremented / decremented
- To increase / decrease the field of the mosaic toward South the DEC- must be incremented / decremented
- To increase / decrease the field of the mosaic toward East the RA+ must be incremented / decremented
- To increase / decrease the field of the mosaic toward West the RA- must be incremented / decremented



Creating wide-field mosaics

Rising of a mosaic project



Tiling scheme indicators

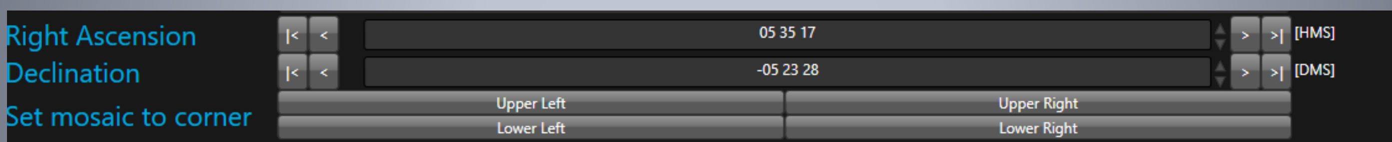
- Shows in real time
  - How the field of the mosaic grows or shrink after editing the tiling scheme settings
  - How the tiling scheme indicators are automatically recalculated

Creating wide-field mosaics
Rising of a mosaic project

- When the sizes of overlap margins between tiles increase or decrease the field of the mosaic grows or shrink in real time

- The field of the mosaic can also be adjusted by a double click on the sky map

- The coordinates of the center of the first tile of the mosaic can be easily adjusted by different options:

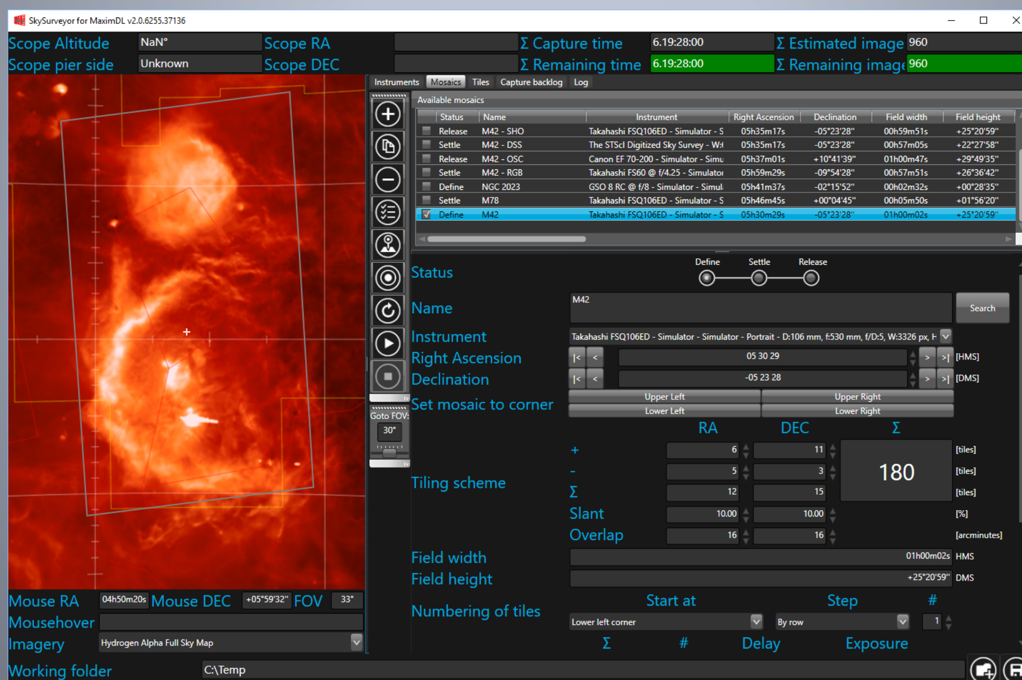


  - Type the coordinate values directly on the corresponding field
  - Slightly increment / decrement the coordinate values with the spinner placed at right side
  - Use the buttons to increase / decrease the coordinate fields or to set coordinate to any corner tile

Buttons	Meaning
<	Decrease the coordinate by the field of one tile.
|<	Decrease the coordinate by the field of the mosaic.
>	Increase the coordinate by the field of one tile.
>|	Increase the coordinate by the field of the mosaic.
Upper Left	Set the mosaic RA & DEC coordinates to the center of the upper left corner tile.
Lower Left	Set the mosaic RA & DEC coordinates to the center of the lower left corner tile.
Upper Right	Set the mosaic RA & DEC coordinates to the center of the upper right corner tile.
Lower Right	Set the mosaic RA & DEC coordinates to the center of the lower right corner tile.

Creating wide-field mosaics
Rising of a mosaic project

- Another cool adjustment feature is the ability to tilt (slant) the mosaic in order to frame the subject as close as possible
- This feature allows to adjust the orientation of the mosaic field without having to change the orientation of the sensor

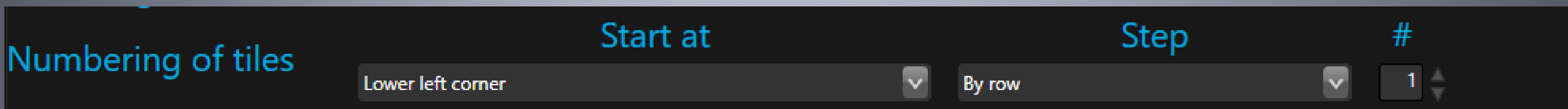


- The slant factors are defined as a percentage of the tile FOV in the selected direction
- For example a slant factor set to 10% means that the center of the next tile will be offset by a value of 10% of the FOV in selected direction

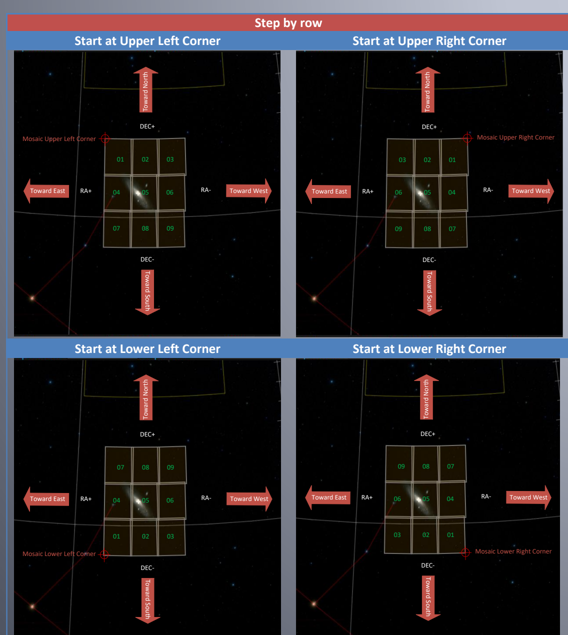
Creating wide-field mosaics

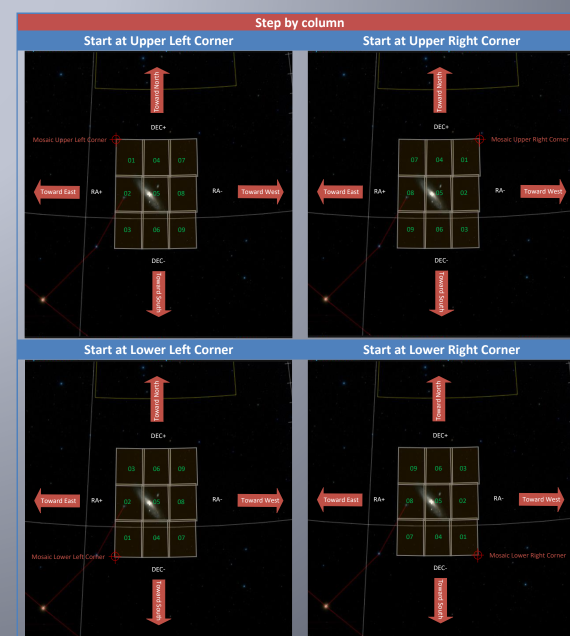
Rising of a mosaic project

- Now, it's time to define how tiles will be numbered



- By default, the first tile begins with 1, the numbering begins with the lower-left corner and the number stepping is row by row
- The following tables show how the tiles will be numbered in various configurations:

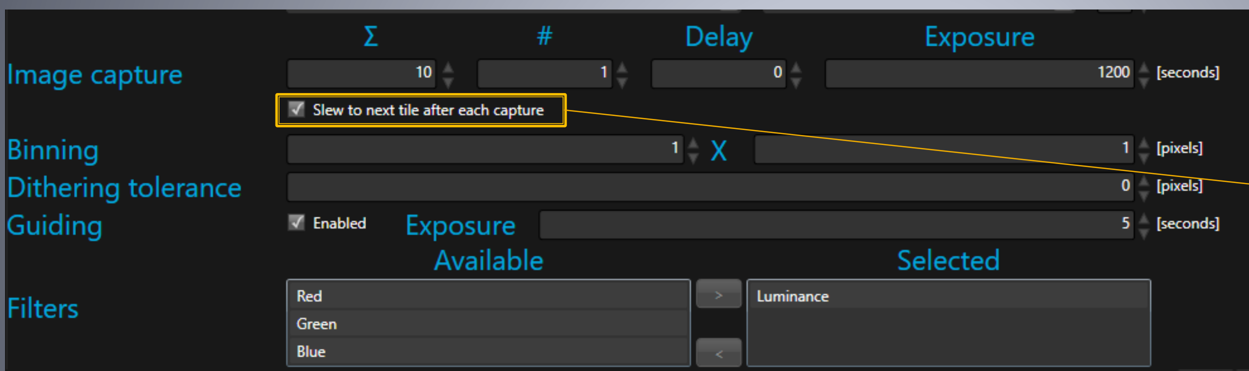




Creating wide-field mosaics

Rising of a mosaic project

- Now this is time to define the capture settings
- Capture settings allows defining how images will be captured for each tile



This option allows to smooth the capture by browsing all tiles during the same night in order to have homogeneous seeing conditions on all tiles.

- Set the number of images per tile
- Set the image start number
- By default there is no delay between each capture, define a delay in seconds if needed
- Set the exposure time in seconds
- By default the binning is set to 1x1, adjust the binning if needed
- By default the telescope stay on the same tile until all subframes for all selected filters have been captured. Slew to next tile after each capture option allows to force the telescope to move to the next tile
- By default the dithering is disabled, define a value in pixels that will be randomly used during capture
- By default guiding is disabled, enable it to start guiding before capture
- If the guiding is enabled, define guider exposure in seconds
- If there is a filter wheel configured for the camera, select filters among the list of available filters given by the selected instrument

- Once all settings are properly defined, the mosaic project can be promoted to the next status

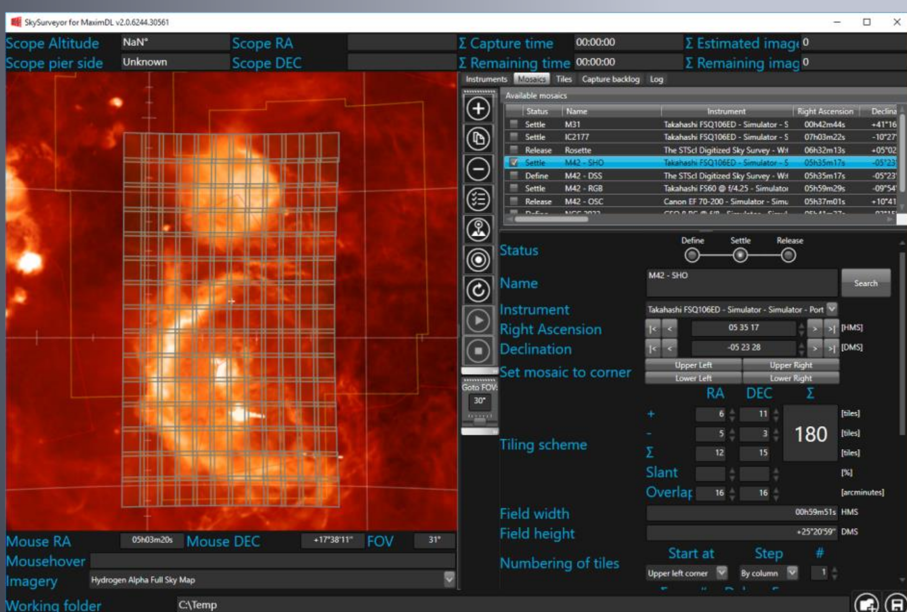
Creating wide-field mosaics

Rising of a mosaic project

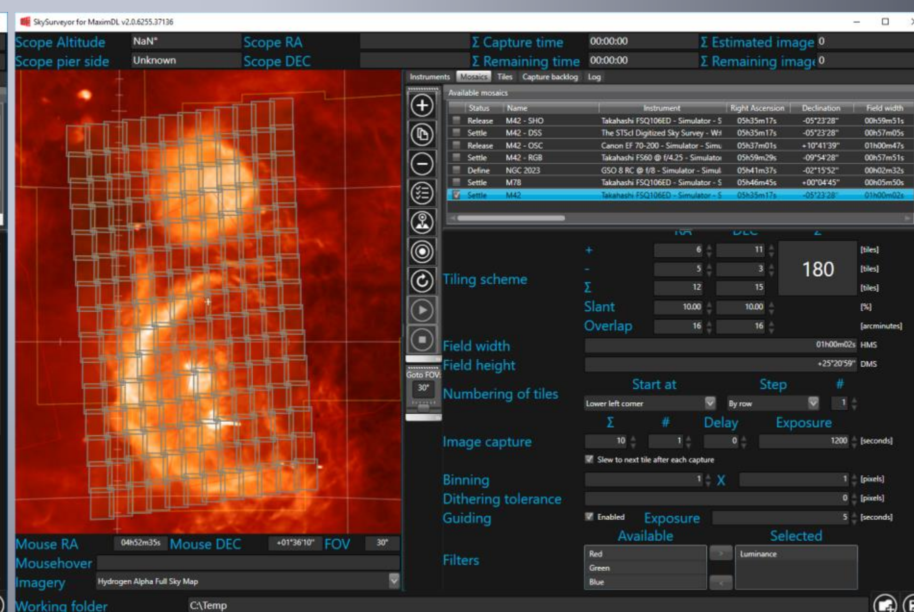
- The “Settle” status allows dividing the mosaic into tiles according the tiling scheme previously defined

- Once the mosaic is divided into tiles, the FOV of every tile including the overlap margins are displayed as graphical overlays on the sky map

- Again, the WYSIWIG interface provides a good preview of how the final result will looks like



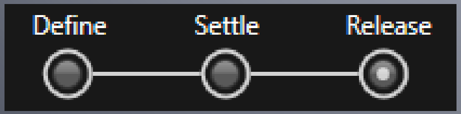
Orthogonal mosaic

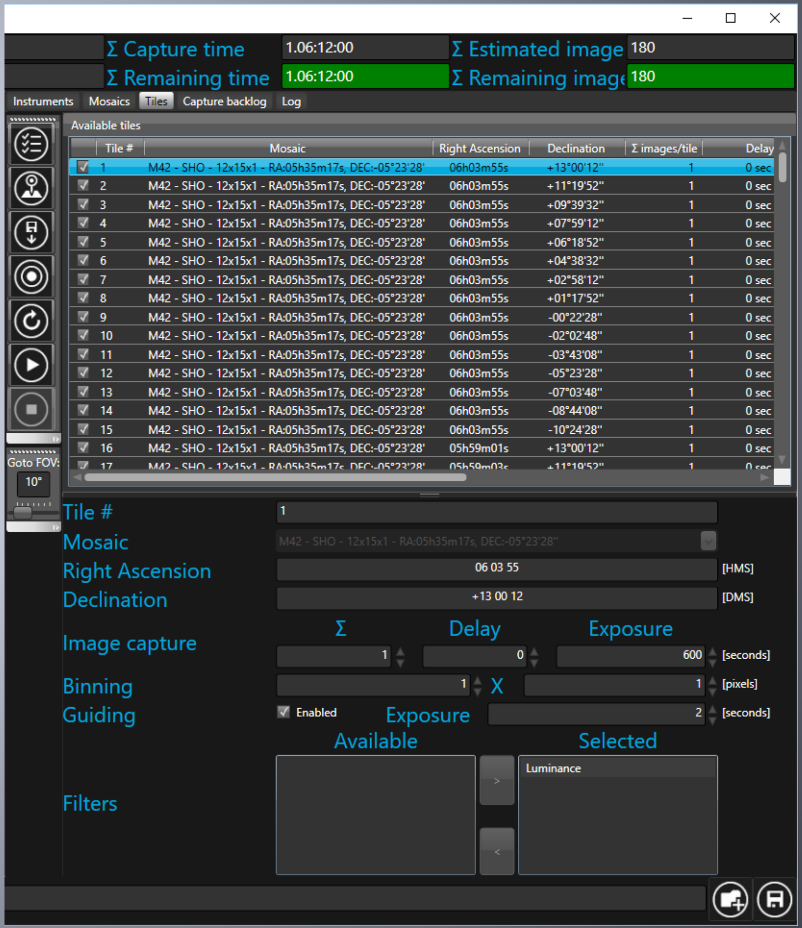


Slanted mosaic

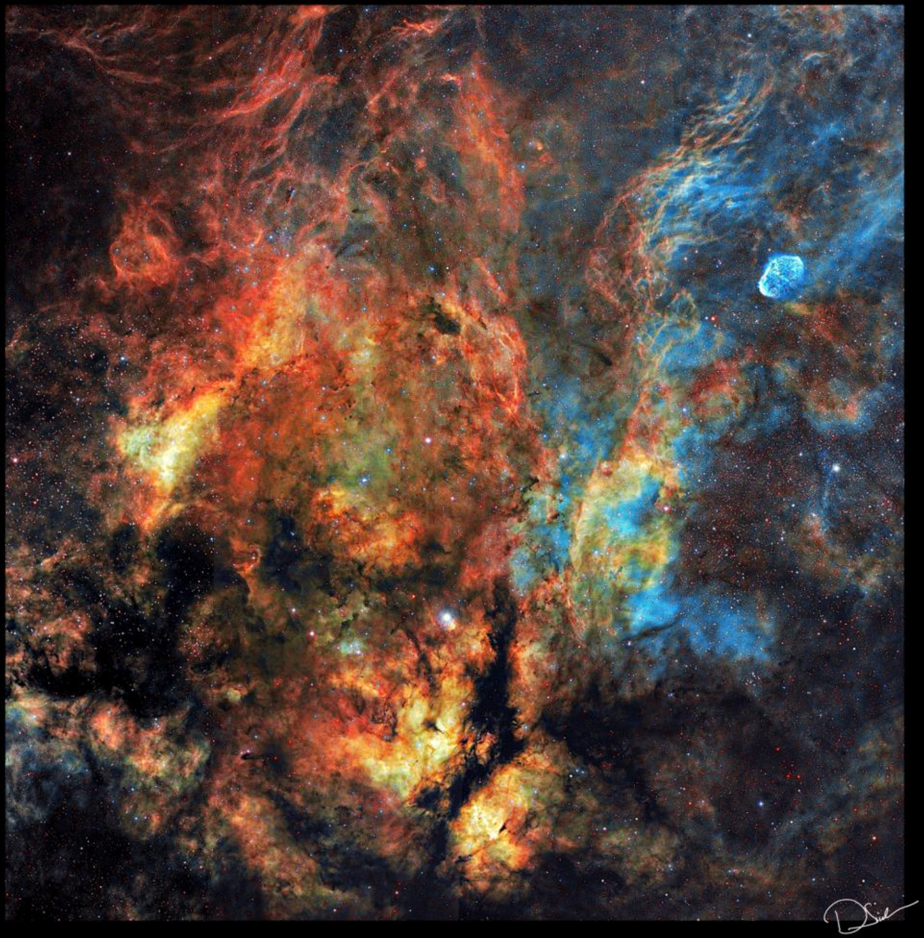
Creating wide-field mosaics
Rising of a mosaic project

- In “Settle” status, the settings of each tiles can be edited individually
- Each tile can be enabled/disabled
- Interactive sky map allows to identify and disable a tile by double-clicking it on the sky map
- The order can also be adjusted by simply dragging & dropping items on the list
- The following settings can be adjusted on each tile:
  - Number of image to capture
  - Delay between each capture
  - Exposure time
  - Binning
  - Enable/Disable guider and the guider exposure time
  - The selected filters
- Once tiles haven been adjusted, the mosaic can be released for capture





NOTE : only enabled tiles will be captured

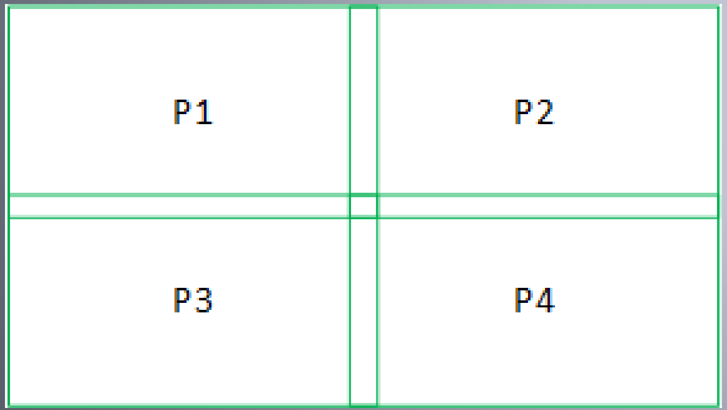


Butterfly and Crescent nebulae (12 panels mosaic)

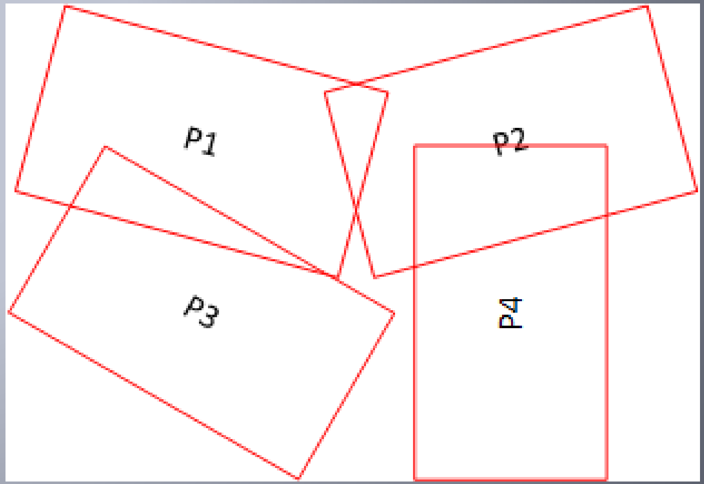
Chapter 2: Sensor alignment

Creating wide-field mosaics
Sensor alignment

- To capture deep sky mosaic we must be sure that the sensors are aligned
- When all panels are parallels the mosaic assembly process and the background level adjustment are simplified

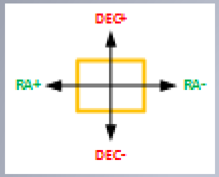
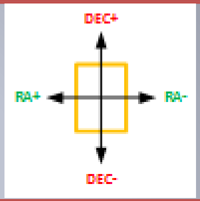


There is no holes (non-captured areas); the margins between the tiles are well defined and regular



There are holes (non-captured areas), the margins between the tiles are irregular

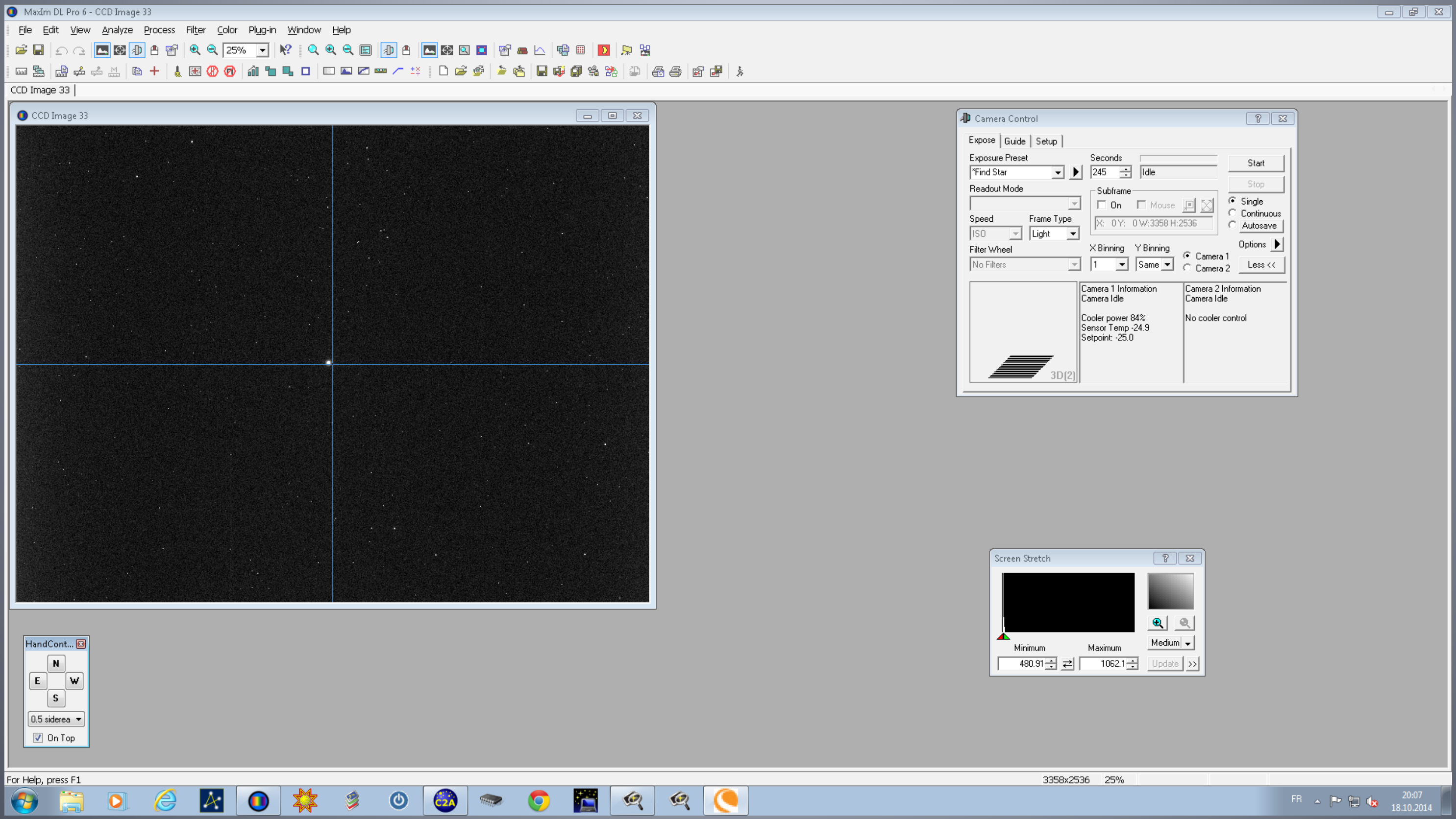
- SkySurveyor is able to work with two sensor orientations

<table>
<tr><th>Landscape</th><th>Portrait</th></tr>
<tr><td>
</td><td>
</td></tr>
<tr><td>In landscape orientation the longer dimension must be parallel to the Right Ascension axis</td><td>In portrait orientation the longer dimension must be parallel to the Declination axis</td></tr>
</table>

- To make sensor alignement, the first step is to assemble the sensor and the optical instrument in such a way that the sensor is as close as possible to the portrait or landscape orientation

Creating wide-field mosaics
Sensor alignment

- Choose a bright star and adjust the focus
- After focus adjustment, move the star to the center of the sensor

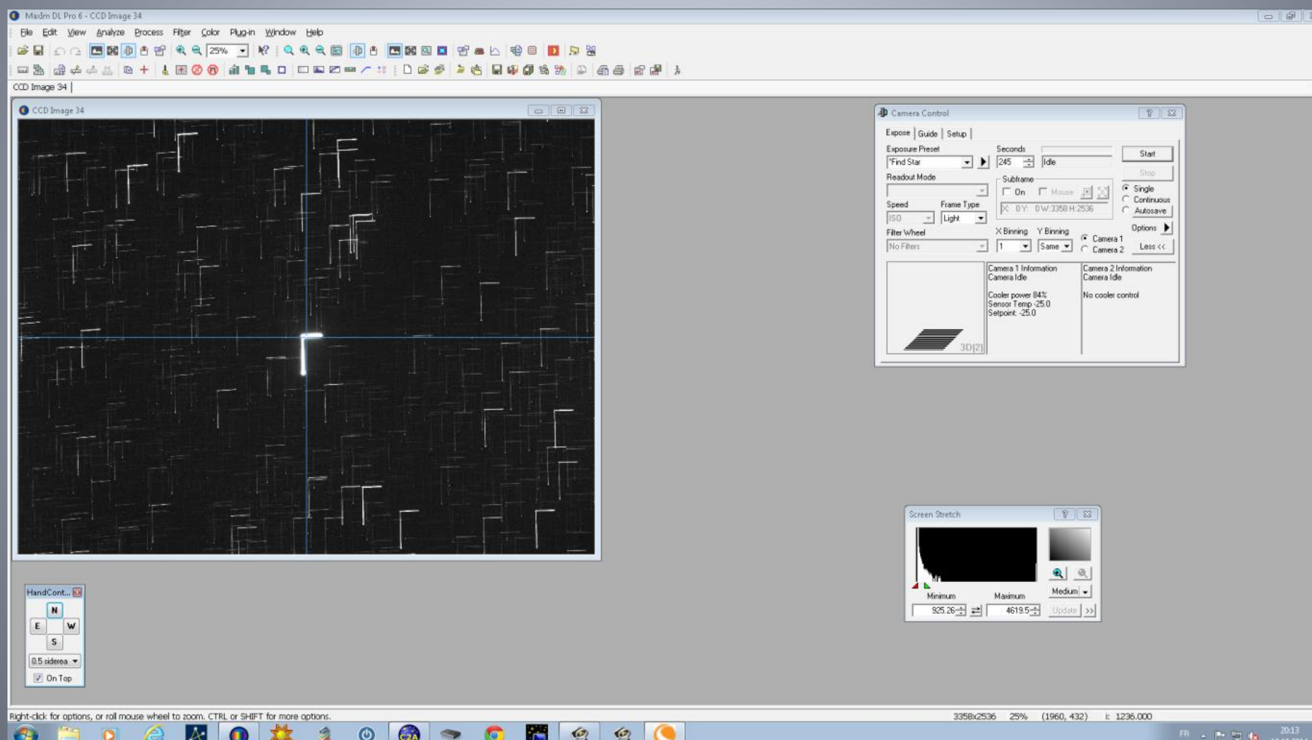


Creating wide-field mosaics
Sensor alignment

- When the star is centered, follow this workflow:
  - Set mount slew speed at 0.5x the sidereal speed
  - Set the exposure time to 245 seconds
  - Start capture
  - Wait 5 seconds before slewing the mount with the mount hand control pad
  - After 5 seconds, press the « E » button to slew mount toward East
  - Keep the « E » button pressed during 65 seconds
  - When 65 seconds has elapsed, press the « W » button to slew mount toward West
  - Keep the « W » button pressed during 60 seconds
  - When 125 seconds has elapsed, press the « S » button to slew mount toward South
  - Keep the « S » button pressed during 60 seconds
  - When 185 seconds has elapsed, press the « N » button to slew mount toward South
  - Keep the « N » button pressed during 60 seconds
  - At the end of the integration time release the « N » button

Creating wide-field mosaics
Sensor alignment

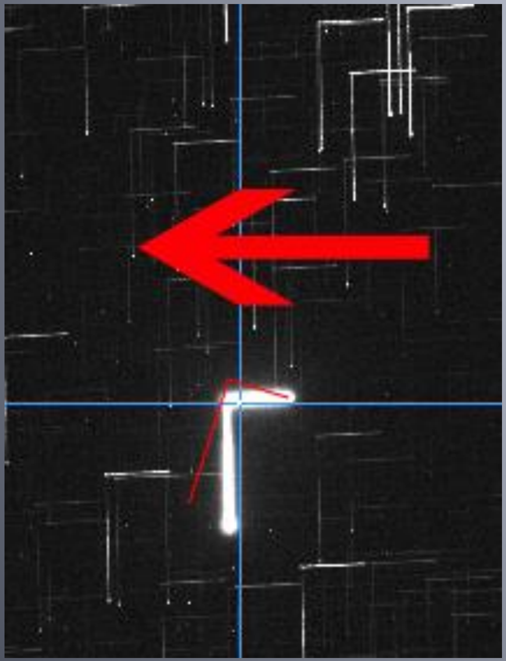
- The move we just did must show a reversed « L » shape at the center of the captured image



- If the reversed « L » shape is aligned with the RA and DEC axis that means that the sensor is well aligned to the equatorial grid

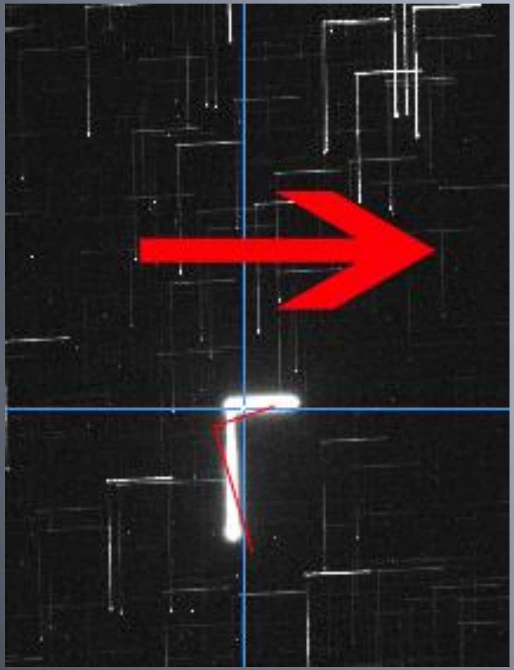
Creating wide-field mosaics
Sensor alignment

- If the reversed « L » shape is aligned like the red one, then slightly rotate the sensor toward the left
  - rotate the camera to the direction indicated by the red arrow

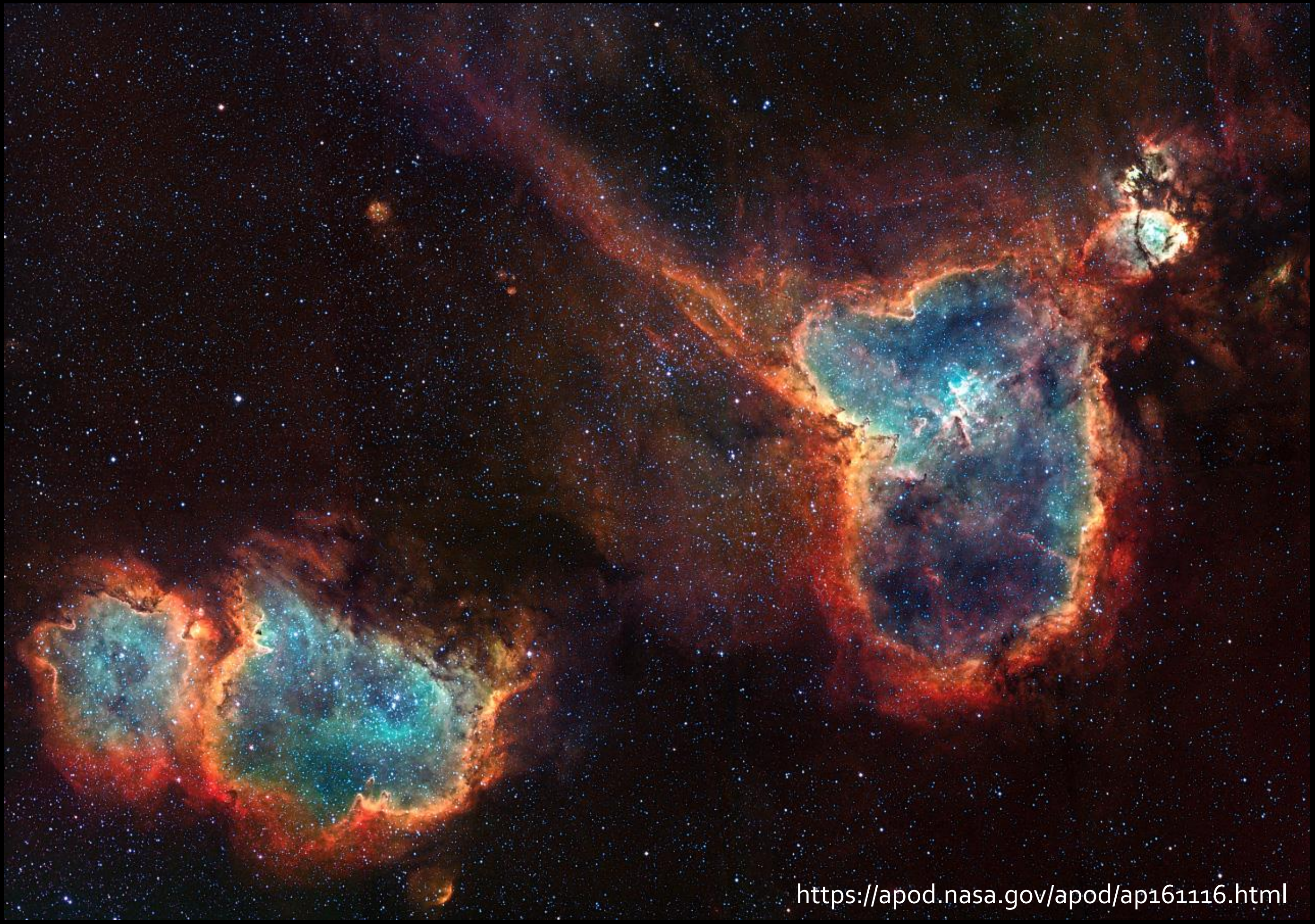


Creating wide-field mosaics
Sensor alignment

- If the reversed « L » shape is aligned like the red one, then slightly rotate the sensor toward the right
  - rotate the camera to the direction indicated by the right arrow



- Once done, restart the procedure from beginning to check if the alignment is correct



Soul and heart nebulae (8 panels mosaic)

Chapter 3: Data acquisition

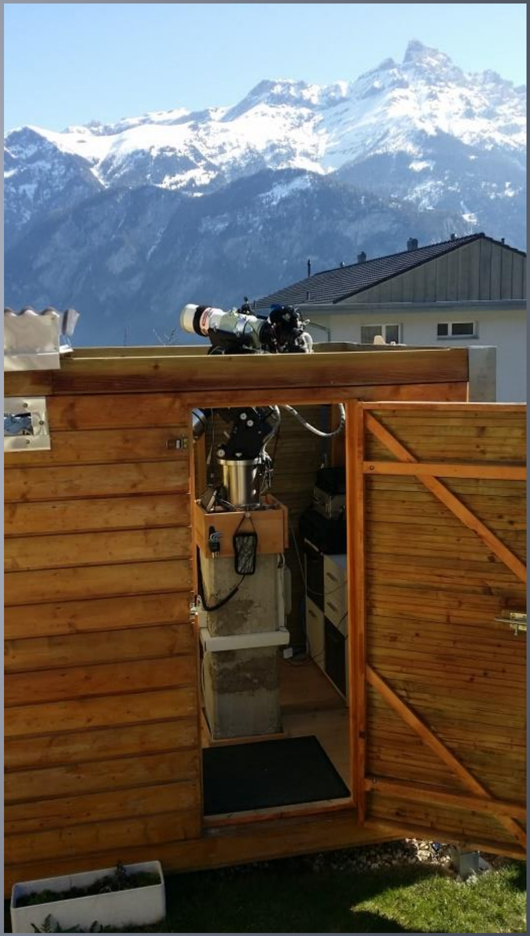
Creating wide-field mosaics
Data acquisition

- The data acquisition is the most critical phase of any astronomical imaging project
  - The main challenge consist of maximizing the clear night time to get the maximum number of subframes
  - During the period where the object is above horizon and located inside the optimal altitude range in the sky
- As a mosaic project is much more demanding in term of total exposure time, number of subframes and telescope targets than a single image project
- As clear nights can happen any time, it becomes very important to be able to optimize data capture as much as possible in order to be able to collect data when conditions are optimal
- To maintain a social life and ability to go to work with a fresh mind while enjoying clear nights to collect photons, I decided to develop an almost fully automated capture process
- To be usable, the automated capture process must be able to answer the following questions:
  - The setup must be ready to capture within a time laps of less than 30 minutes?
  - The system must be able to move the telescope mount to each targets automatically?
  - The system must be able to monitor in real time the weather conditions and the health of the setup during the capture process?
  - The system must be able to notify me without delay in case of any event
    - unsafe weather conditions
    - trouble with the setup or with the capture process?
  - The instrument must stay perfectly focused during the full night without human intervention and interruption of the capture process?

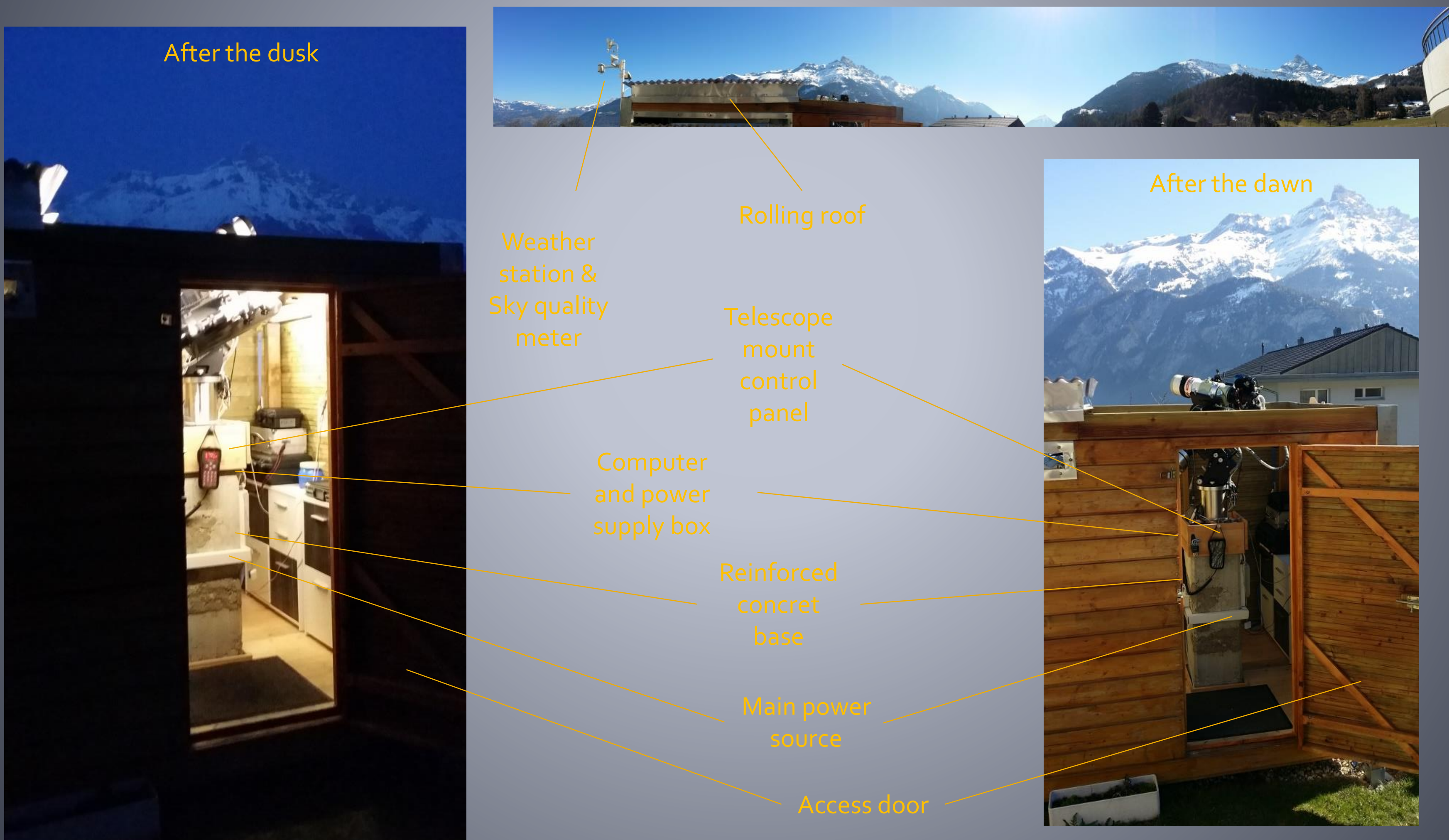
Creating wide-field mosaics
Data acquisition

CEDIC

- To be usable (continued):
  - Each captured subframe must be automatically named in order to help me during the image selection, calibration, registration, integration and stitching?
  - The setup must be shutdownable and placed in safe state in less than 5 minutes?
  - The system must be able to restart the capture process at the same state it was stopped last time and must be able to continue data capture according the predefined capture plan?
  - The mount must be able to make the pier flip without human intervention and interruption of the capture process?
- The first challenge in my way to automate the capture process was to build a shelter for my setup
- In 2013, I started to build a shelter with rolling roof and reinforced concrete base to hold my setup
- On top of the concrete base, I have installed a high end 10micron GM2000 robotic telescope equatorial mount
- On both parallel dovetails I have installed a Takahashi FSQ 106 apochromatic refractor and a GSO RC 8” reflector



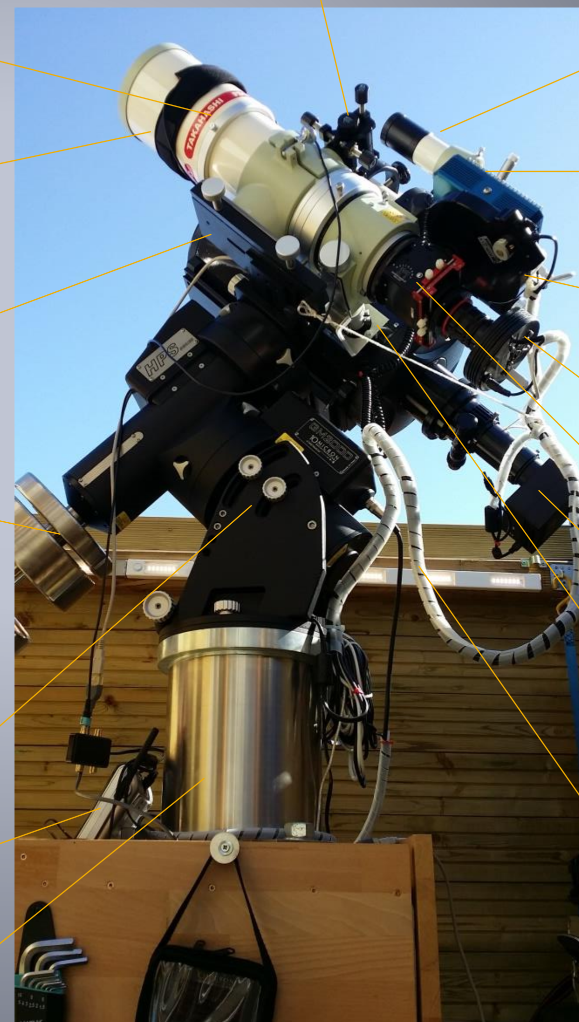
Creating wide-field mosaics
Data acquisition



CEDIC

Creating wide-field mosaics

Data acquisition



Main Imager Apo Refractor

Dew remover

Parallel dove tails for two instruments

Mount counter weights

10micron GM2000 Robotic Telescope Equatorial mount

Weather station comptuer

Custom Inox steel extender

Telelens mounting plate

Finder Scope

Main Imager Camera Apogee U8300 Monochrome

Main Imager filter wheel

Guiding Camera

ONAG XT

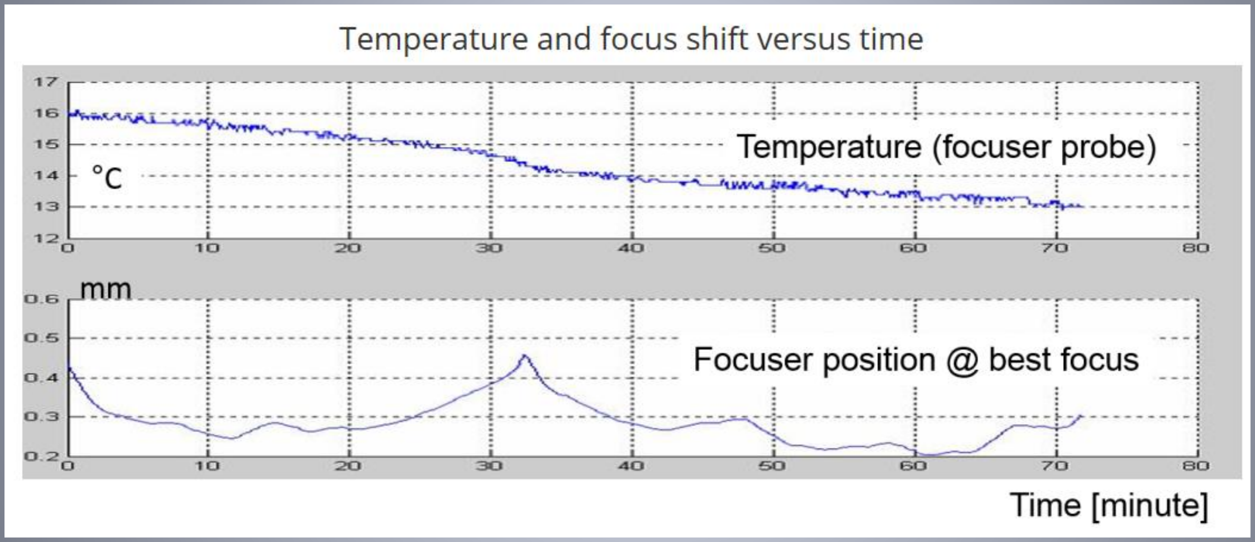
Color Camera Moravian G2-8300

Electronic USB controlled focuser

Cameras power supply umbilical cord

Creating wide-field mosaics
Data acquisition

- Experienced astrophotographers knows that the focus shift when the temperature is changing

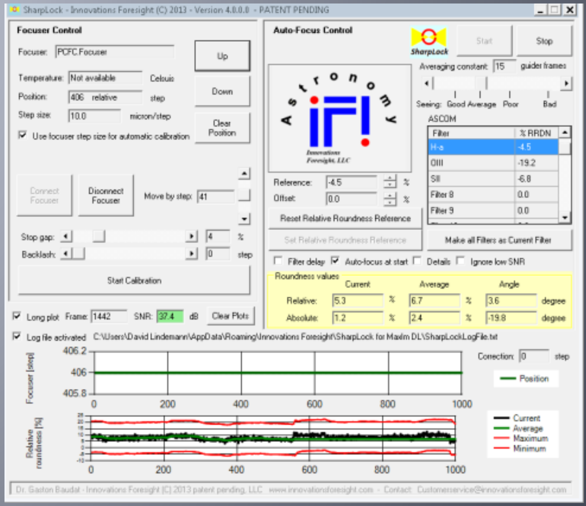


- To keep their instruments perfectly focused along the full night, the experienced astrophotographers refocus them several times a night
  - This task requires at least an interruption of the capture process and most of the time a human intervention
- My second challenge was to find a solution that keep my instruments perfectly focused during the capture time without interruption of the capture process and without human intervention

Creating wide-field mosaics

Data acquisition

- After my speech at NEAIC 2015 in New York, I met a compatriot who lives in USA and who developed wonderful piece of engineering called ONAG XT
- The ONAG® XT is a full frame On-Axis guider (up to 50mm diagonal): https://www.innovationsforesight.com/products/full-frame-on-axis-guider-onag-xm-unit-only/
- The ONAG® and software called SharpLock® allows keeping the instrument perfectly focused along the full night in a fully automated way
- The auto-focus operations are done in real time during the exposure by measuring the shape of the guide star and moving the focuser to restore the best focus

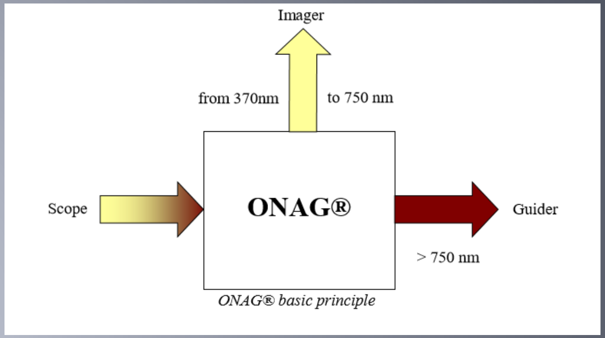


Creating wide-field mosaics
Data acquisition

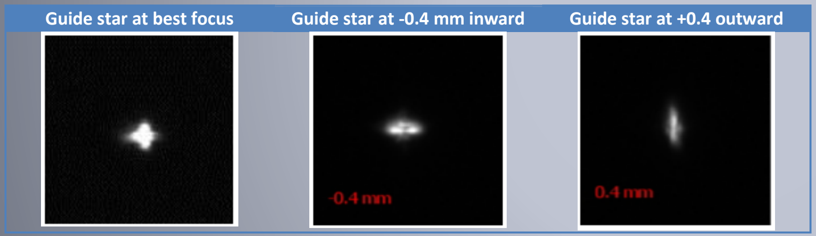
- How it works :

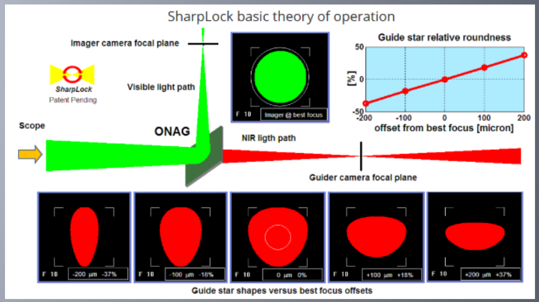
  - The light coming from the scope enter in the ONAG® the visible light (from 370 to 750 nm) is reflected to the imager sensor and the infrared light (>750 nm) goes through the dichroic mirror

  - Due to astigmatism caused by the dichroic beam splitter the shape of the guide star change according to the position of the focal point



ONAG® basic principle





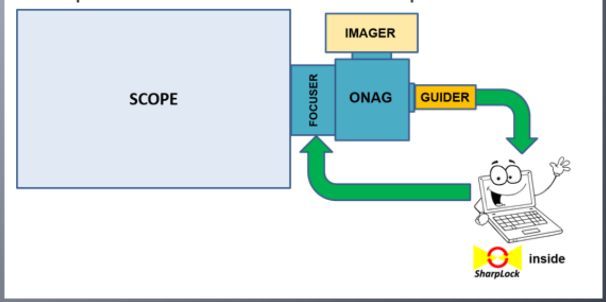
  - The software SharpLock measures the shape of the guide star at the rate of the exposure time

  - When the shape of the guide star shows a trend that goes inward, SharpLock® moves the focuser outward to restore the best focus

  - When the shape of the guide star shows a trend that goes outward, SharpLock® moves the focuser inward to restore the best focus

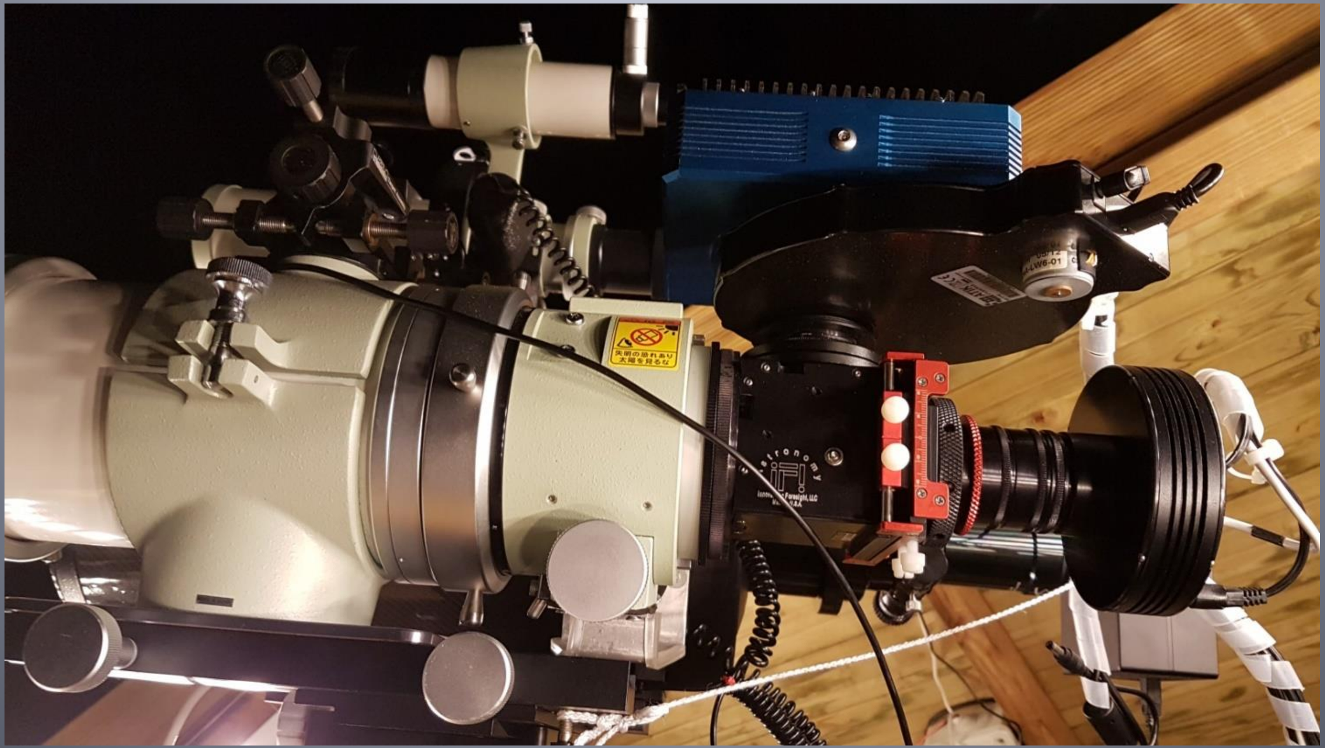
  - The focuser move steps are very small and they can occur while capturing the image without any artifacts on it

SharpLock real time closed loop auto-focus



Creating wide-field mosaics
Data acquisition

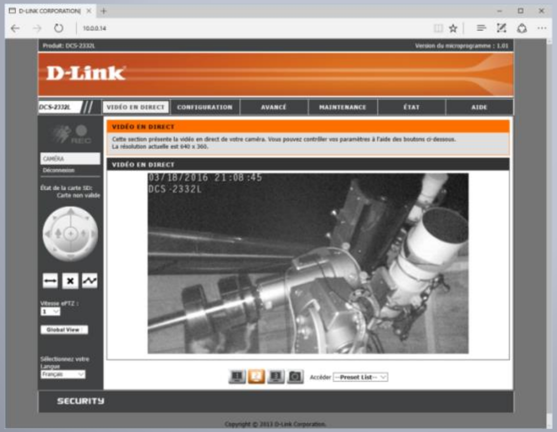
- Another advantage provided by the ONAG is the stability of the infrared light
- IR light is less distorted by atmospheric effects than the visible light
- The guiding and the focusing are more accurate with IR light than visible light

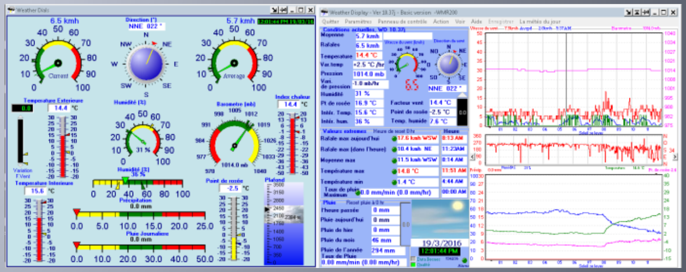


Creating wide-field mosaics
Data acquisition

- The third challenge was to build a control center allowing to remote control and monitor my setup while capturing

- To do that I have installed an Intel® NUC computer inside my observatory



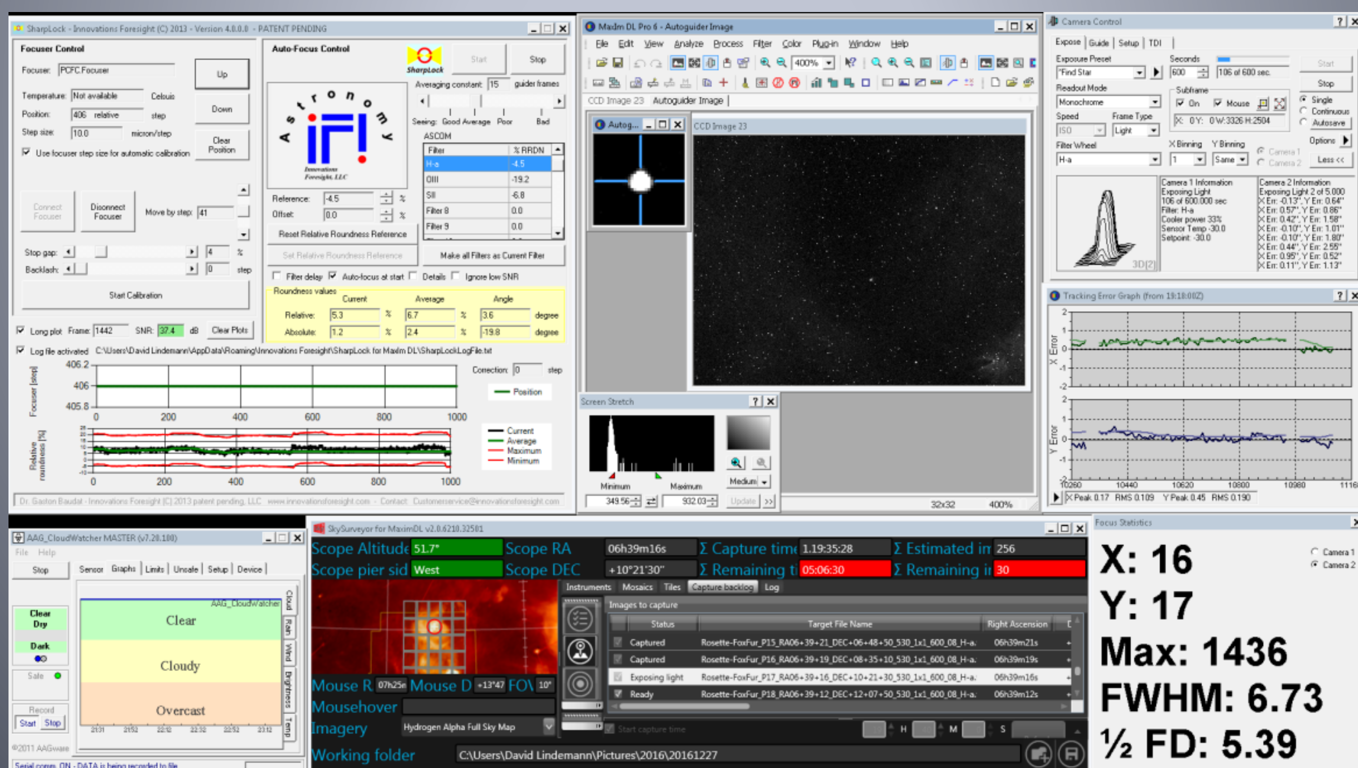


- To monitor my setup while slewing, I have installed an IR cam inside my observatory

- To monitor the weather condition, I have installed a weather station, a sky quality meter and weather monitoring software

Creating wide-field mosaics
Data acquisition

- On the observatory computer, I have installed the following software:
  - MaximDL 6
  - SharpLock 1.0
  - AAG Cloud Watcher 7.20 (sky quality monitoring)
  - Weather Display 10.37j (weather conditions monitoring)
  - SkySurveyor 2.0



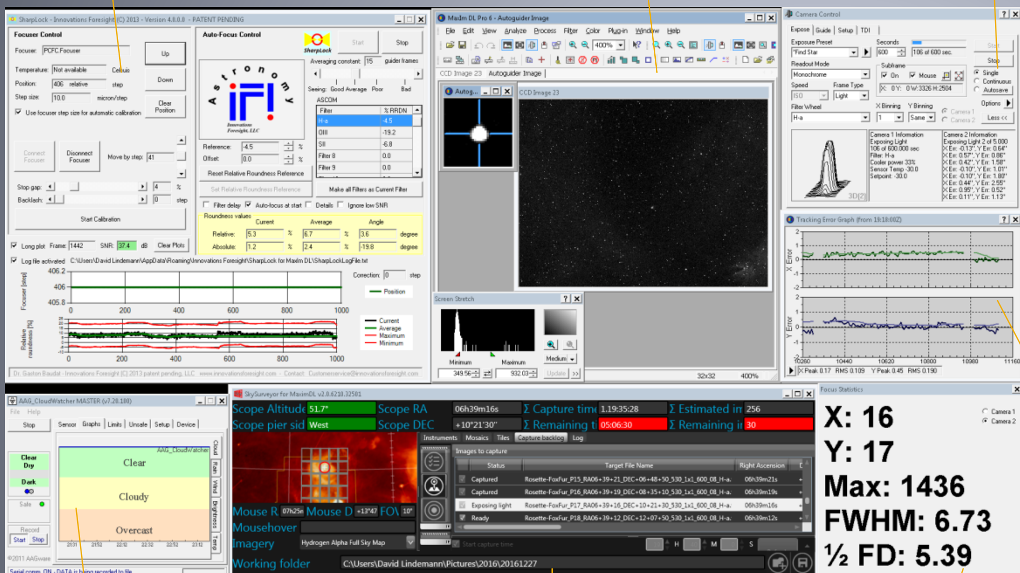
Creating wide-field mosaics

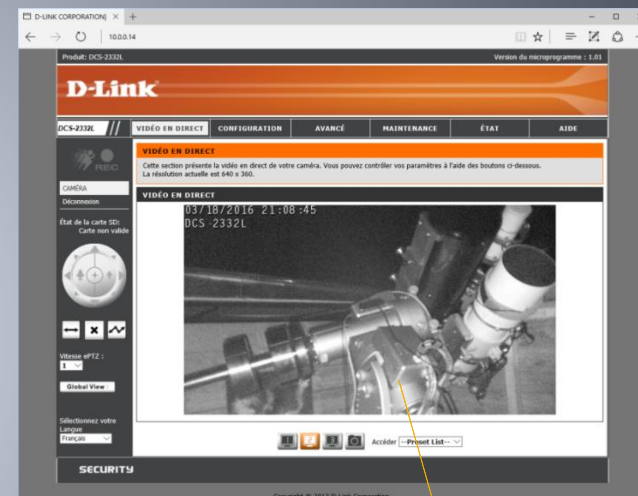
Data acquisition

Focus control

Image capture monitoring

Camera control





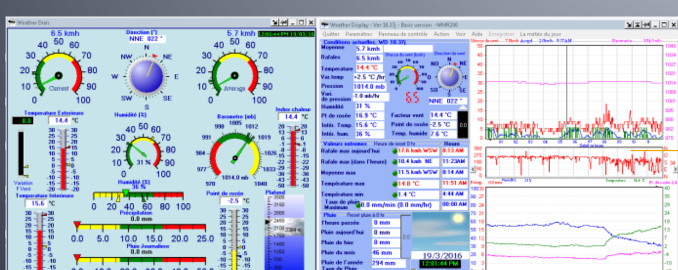
Guider error monitoring

Infrared scope cam

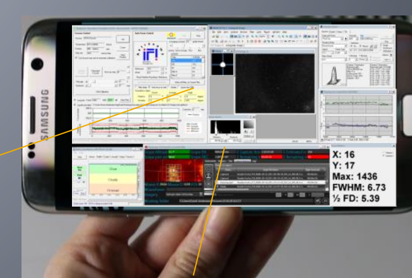
Sky quality meter through infrared sensor

Mosaic capture control

FWHM monitor
Sky quality monitoring through guider



Weather station control

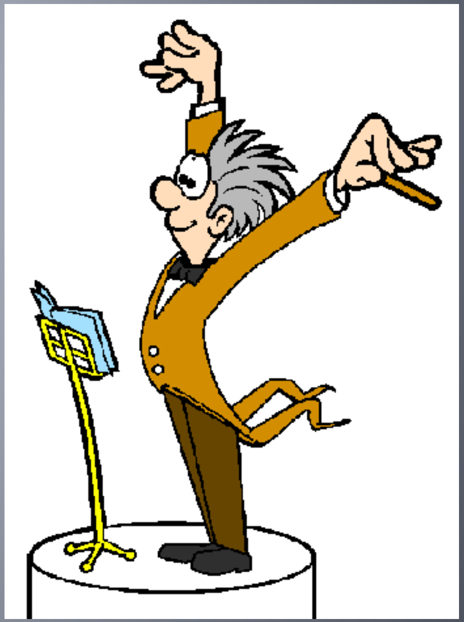


Remote control

Unsafe condition and guide star faded feedback via push notifications

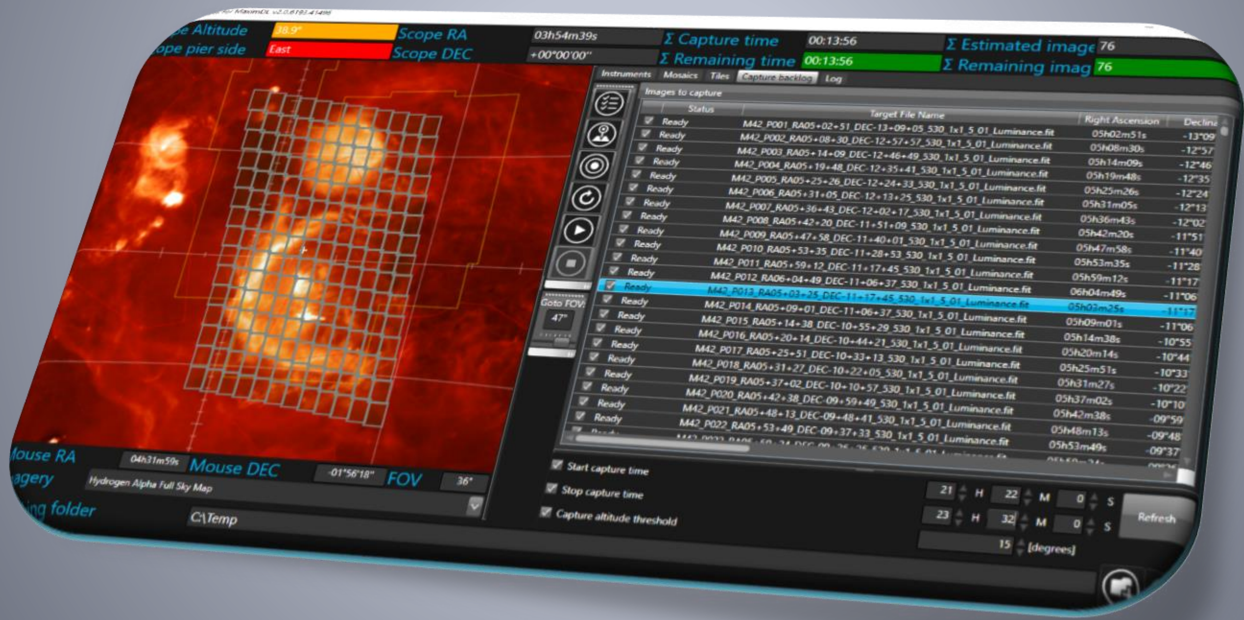
Creating wide-field mosaics
Data acquisition

- The last challenge was the orchestration of the data acquisition process
- What does the orchestration means?
  - Scheduling the capture process
  - Following the predefined capture plan
  - Giving a real time feedback that shows the field being captured as a graphical overlay on the sky map
  - Giving indicators that show the telescope position, the mount pier side, the telescope altitude, the remaining capture time, the remaining number of images that must be captured, etc.
  - Operating the telescope mount to automatically slew to the target coordinates
  - Acquiring a guide star
  - Starting the guider before exposing light
  - Moving filter wheel to the selected filter
  - Exposing light
  - Retrieving the captured image
  - Storing every image on the hard drive with a helpful naming convention
  - Stopping the guider before operating the telescope mount
  - Monitoring the scope position, guide star, the sky quality and the weather conditions
  - Sending notifications to smartphone in case of any trouble
  - Managing the equatorial mount pier flip
  - Capture only tiles that are above a given altitude
  - Logging all events that occurs while capture in a text file



Creating wide-field mosaics
Data acquisition

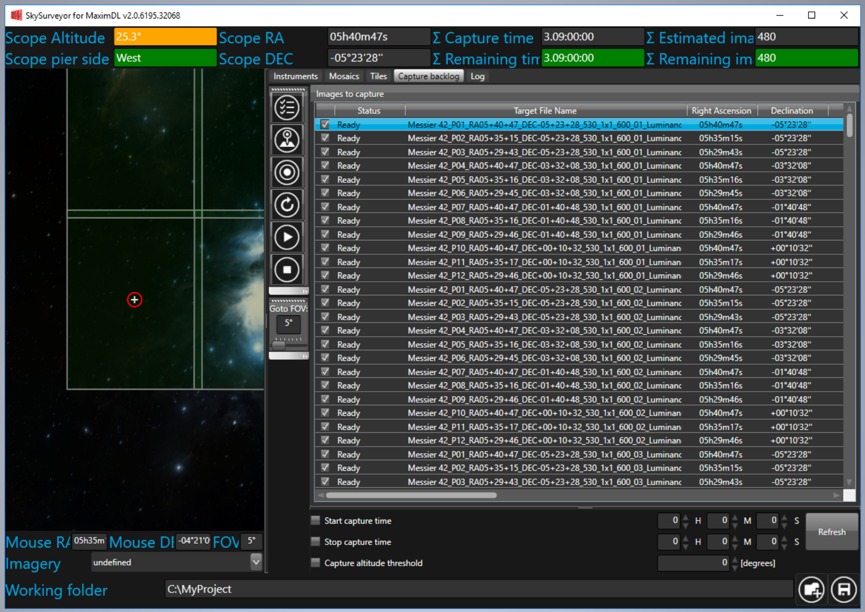
- This is done by SkySurveyor



- When a mosaic project is released for capture, the capture backlog is filled with a list of capture task
- There is one capture task per single subframe

Creating wide-field mosaics

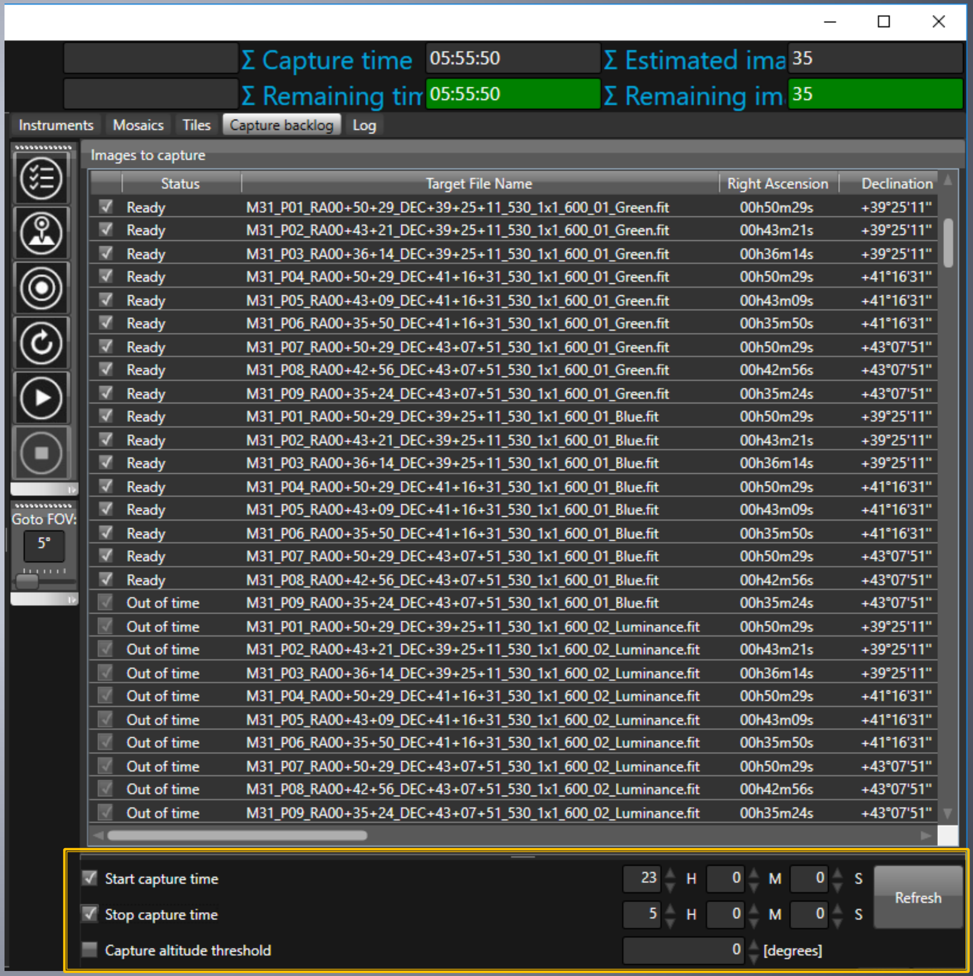
Data acquisition



- While capture all tasks are processed from top to bottom and the interactive sky map move to the target tile and shows the telescope position in real time
- The capture indicators on top of the user interface are updated in real time
- The telescope position is marked by a red circle on the sky map
- This is very useful to monitor the capture process and to know which tile is being captured

Creating wide-field mosaics
Data acquisition

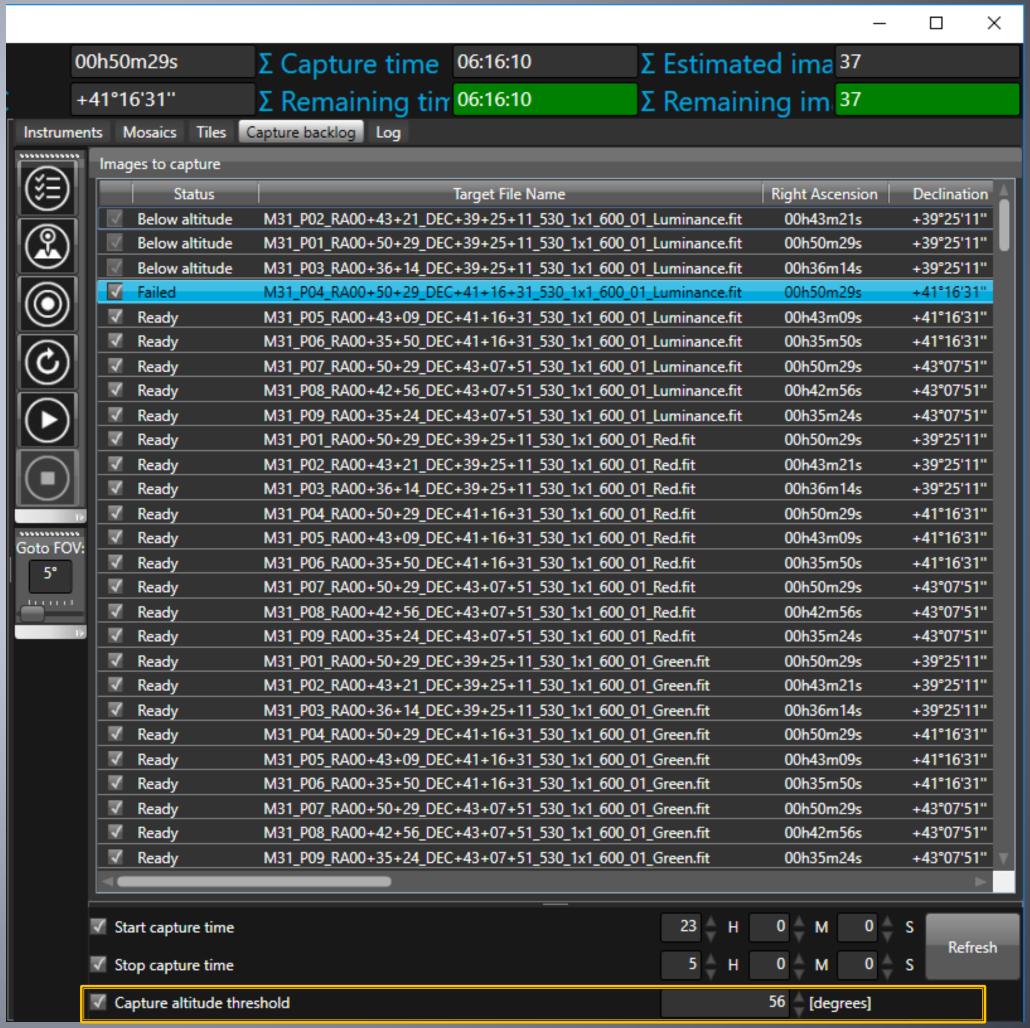
- SkySurveyor allows defining constraints that can be applied at capture
- These constraints allow to define …
  - A time frame
  - An altitude threshold that must be reached
- If the project requires several nights, the time frame constraint help to predicate how many image will be captured during each night
- As an example the start capture time is set to 23h00 and the stop capture time is set to 5h00
- All tasks that exceed the defined time frame are displayed in the list with the status “Out of time”
- All tasks with the status “Out of time” will not be captured and the capture indicators are automatically adjusted to shows what will be exactly captured during the time frame



Creating wide-field mosaics

Data acquisition

- All tasks that are below the minimum altitude are displayed in the list with the status “Below altitude”
- All tasks that are below altitude are temporarily skipped and will be processed later on



Creating wide-field mosaics

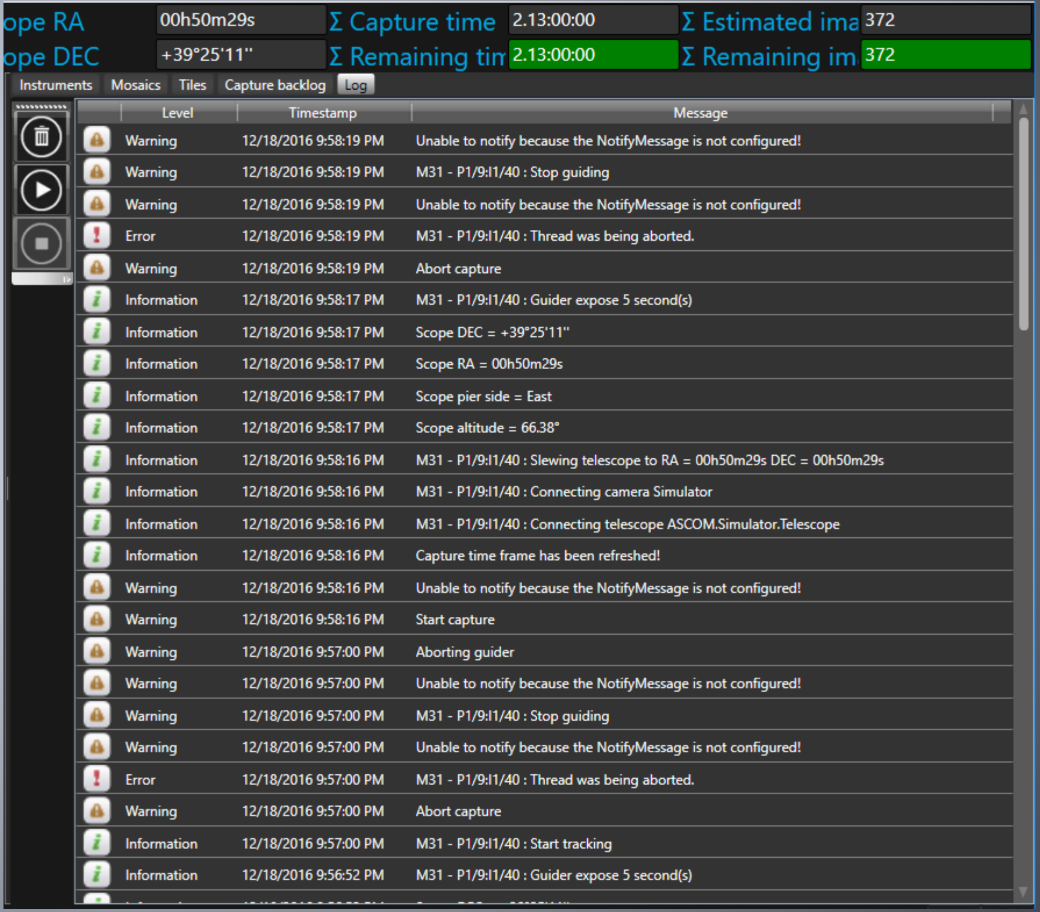
Data acquisition

- All operations that are done and all events that occur while captures are automatically logged into a text file and displayed in the user interface into an interactive list

- The last operation or event that happened is inserted on top of the list

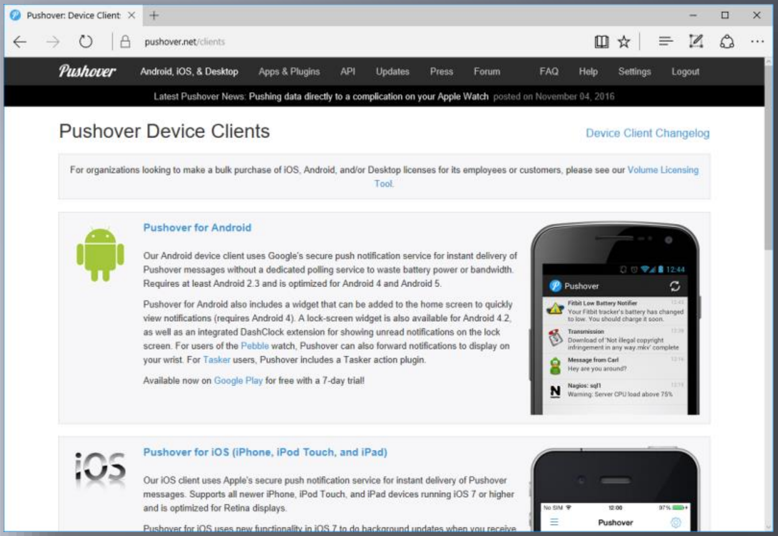
- The capture process can be stopped at any time and restarted later

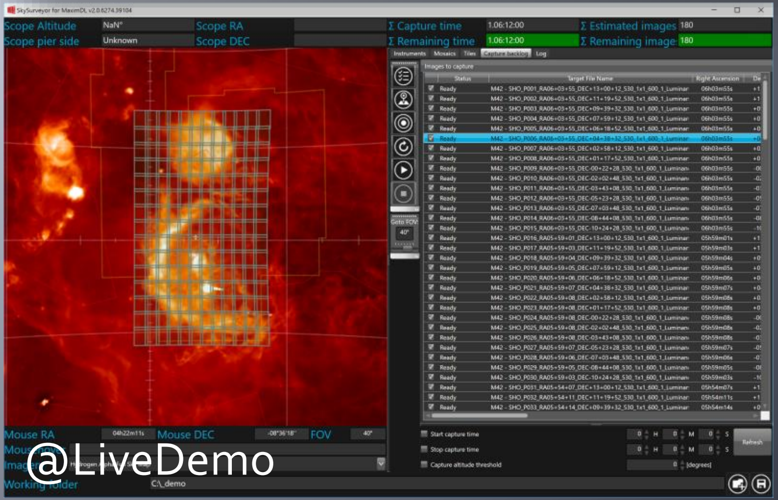
- When restarting the capture process the system automatically remember the state where it was last time and continue to capture the remaining tasks until the end



Creating wide-field mosaics
Data acquisition

- SkySurveyor is able to send notifications directly to a smart phone via Pushover®
- This feature is very useful to warn in case of trouble while capturing
- With this cool feature, I am not be worried if I sleep during the capture process because in case of trouble the system will automatically wake me up
- The following events can be notified:
  - If the target coordinates of a tile cannot be reached
  - If the guide star is faded during a configurable number of iterations
  - In case of any failure that occurs while capturing
  - When capture is started
  - When capture ends
  - When capture is aborted
  - If the sky quality is below a predefined threshold
  - If the wind speed exceed a given speed
  - If the sky become overcast or if it rains





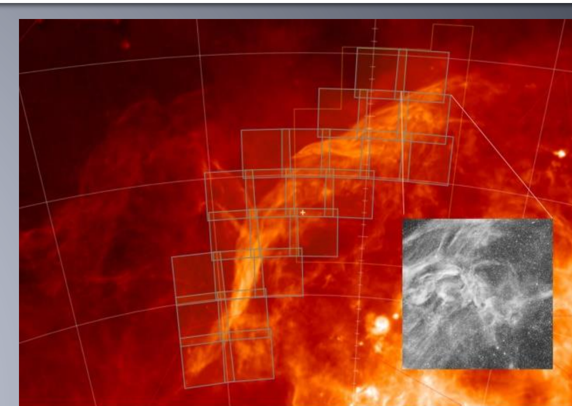
Creating wide-field mosaics
Testimonial

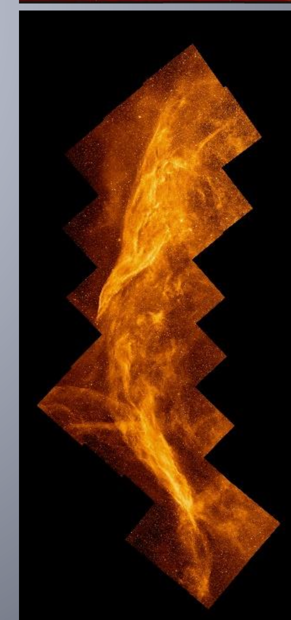
- Author, World Renowned Astrophotographer
- John Gleason's life long passion has been wide field, highly detailed astrophotography - in particular sweeping grayscale vistas of hydrogen alpha emission objects along the galactic equator. Over the last 5 years, John Gleason has embarked on a photographic odyssey to produce a personal CCD atlas of very deep H-a portraits of northern and southern hemisphere emission nebulae
- He has accepted to be my first beta tester for SkySurveyor V2
- As a first trial, He did a mosaic project on the Gum complex in Vela
- He send me the following testimonial :

The data capture is easy but this is not a novice software for a beginner. I think it requires a pretty good knowledge of your full imaging system. But that is no different than most of the astronomical software that is out in the market. For me, the planning aspect around the H-a sky map is priceless. I can layout what I want to do and see how it will look. What you see defined on the map is what you get!

I have also used the sky map to add tiles to existing mosaics by simply creating a new mosaic in Surveyor and entering the known RA and DEC from one of my original tiles. Then I can add new tiles in RA and DEC and be confident that I can mate them to the original mosaic. My 54 segment Orion mosaic was recently completed this way.

Also….. my typical tile overlap is 40 arc minutes with the FSQ and 16803 at f/5, but because of the precision of this entry in Surveyor, I can probably reduce that to 30 to 35 arc minutes. Slightly wider coverage in a large array.





The northern edge of the Gum complex by John Gleason

FSQ @ f/5, Proline 16803, 5nm
Ha. 1800s x 6 each tile

If you want to get a free release of SkySurveyor just send an email to : david.lindemann@netplus.ch

Rosette nebula

Chapter 4: Preprocessing (Calibration)

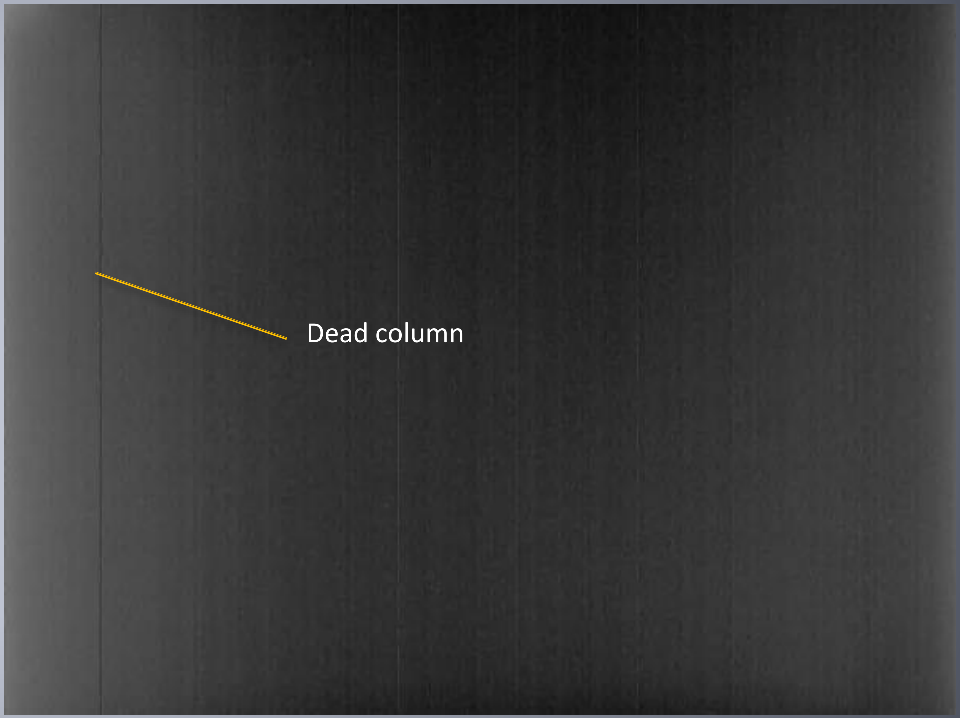
Creating wide-field mosaics
Preprocessing (Calibration)

- A proper calibration is a very important step in astronomical image processing
- It must be done as best as possible to avoid loss
- Indeed, poor calibration is very destructive for the raw data and without calibration the noise and the optical train artifacts remains
- All monochromatic images acquired by the capture process must be calibrated
- They are called Light frames

A light frame on Rosette nebula captured 28.12.2016 with Takahashi FSQ 106 @ f/5, Astrodon 5nm H-alpha filter, and Apogee Alta U8300 monochrome cooled at -30° for 600 seconds of integration time

Creating wide-field mosaics
Preprocessing (Calibration)

- Dark and Bias frames are used to calibrate the Light frames
- They are taken in total darkness with the camera shutter closed or the lens covered
- The dark frame contains the bias signal and the thermal signal
- The thermal signal is the noise (dark current) that is summed over the length of an exposure
- The dark frames must be taken at the same temperature during the same integration time to properly characterize the thermal noise generated by the electronics of the sensor
- Subtracting the thermal signal allows to remove the majority of noise from a light frame
- Subtracting the dark also allows equalizing the signal by removing dead columns and dead pixels
- Dark frames are the more demanding calibration data because it requires several hours to generate them

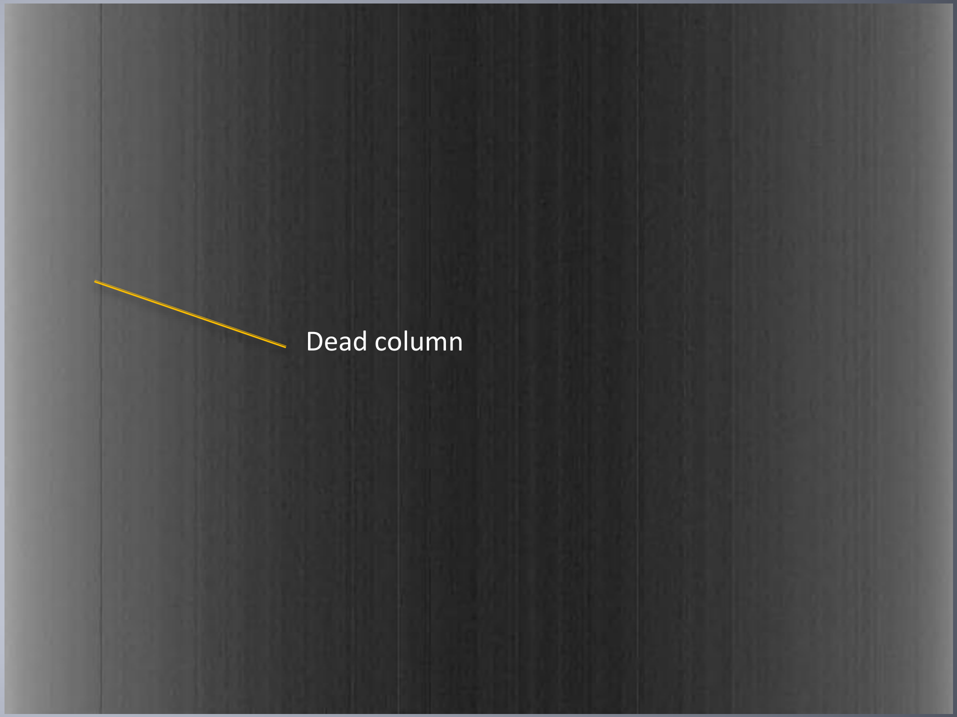


A master dark built from 50 dark frames captured with Apogee Alta U8300 monochrome cooled at -30° for 600 seconds of integration time

Creating wide-field mosaics
Preprocessing (Calibration)

- Bias is similar to a Dark but it does not contain the thermal signal

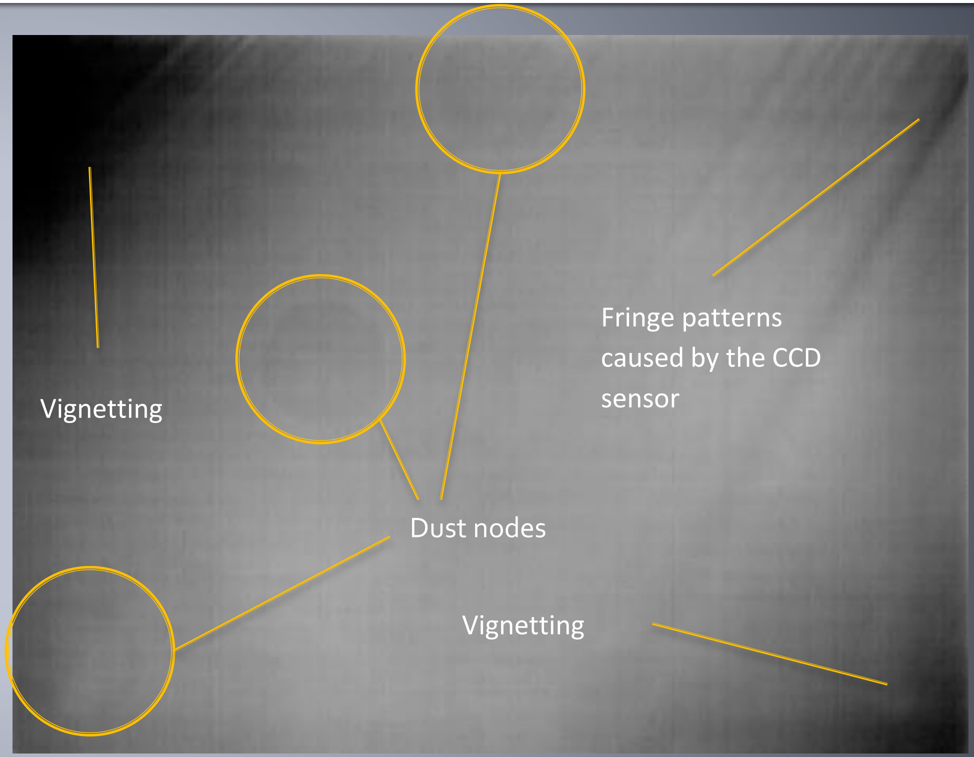
- High end cameras having regulated cooler does not need bias if the temperature and the exposure time used to capture dark and flat frames are equivalent to the temperature and the exposure time used to capture the light frames



A master bias built from 50 bias frames captured with Apogee Alta U8300 monochrome cooled at -30° for 0 seconds of integration time

Creating wide-field mosaics
Preprocessing (Calibration)

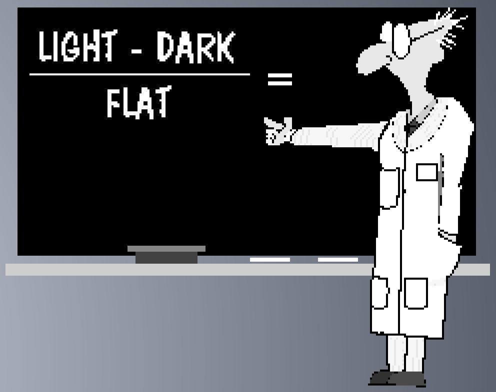
- Flat frames allow making the portrait of all imperfections (artifacts) that occurs on the components that are parts of the optical train
- Unlike the dark and bias, flats are taken in presence of uniform light
- This can be the natural light of dusk or dawn or artificial light emitted by an electroluminescent panel
- I use an electroluminescent panel because it is much easier than using the natural light



A master flat built from 50 flat frames captured with Takahashi FSQ 106 @ f/5, Astrodon 5nm H-alpha filter, Apogee Alta U8300 monochrome cooled at -30°, and an electroluminescent panel

Creating wide-field mosaics
Preprocessing (Calibration)

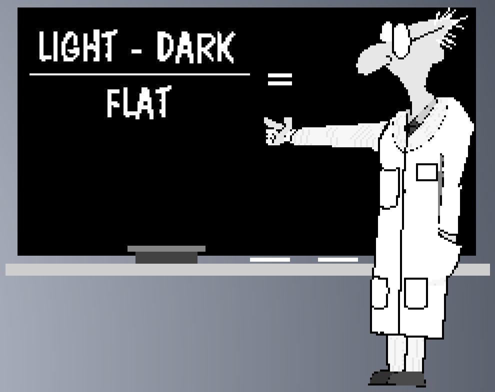
- A proper calibration must be done by subtracting the master dark from the light frame and by dividing the subtraction result by the master flat



- If the light frame is taken with different temperature or exposure time than the master dark frame
  - a series of bias frames must be taken at the same temperature than the light frames
  - This series of bias frames must be combined to get a master bias frame
  - The resulting master bias frame has to be integrated to the calibration process to make an adaptive subtraction of the preexisting dark frame

- Usually, I never use adaptive subtraction. I always prepare my master dark and flat at the same temperature and with the same integration time that I have used to capture the light frames
  - I build and maintain a library containing all my calibration masters for all my instruments and for all the exposure, binning configuration and filters that I regularly use

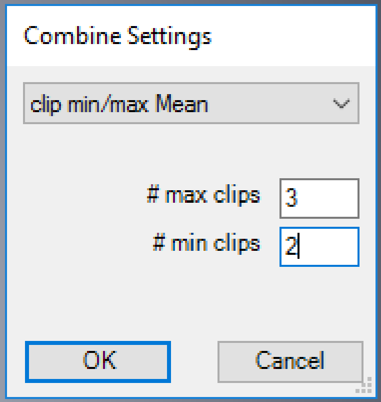
Creating wide-field mosaics
Preprocessing (Calibration)



- To follow the evolution of my sensors along the time, I redo my calibration masters every 6-8 months
- I take 50 frames of each kind of calibration frames (darks and flats) with the camera cooled at -30°C
- I use the software CCDStack® to build my calibration master
- To create a master dark, I use the create calibration master command in CCDStack
- This command allows generating clean dark master that can be used during several months
- Clean master dark, means that the cosmic rays that occur especially on long exposure must be removed to do not add unexpected noise to the light frame during calibration

Creating wide-field mosaics
Preprocessing (Calibration)

- To generate clean dark master, CCDStack offers a good combining algorithm called “Clip Min/Max mean”
- This means that the highest and lowest pixel values are ignored from the series of 50 frames. The remaining 45 values are averaged to create the master dark
- As cosmic rays are transient events that they occur only once, the resulting master dark is then free of cosmic rays
- Once the master dark is done, the next step is the generation of master flat
- To make a master flat, I also use 50 flat frames captured with an electroluminescent panel
- I capture 50 flat frames per filter available on my filter wheel
- The exposure time of each flat frame is adapted to the selected filter to avoid saturation
- To create a master flat, I use the create calibration master command in CCDStack
- This command subtracts the bias frame from each flat frame and then it averages the values to create the master flat



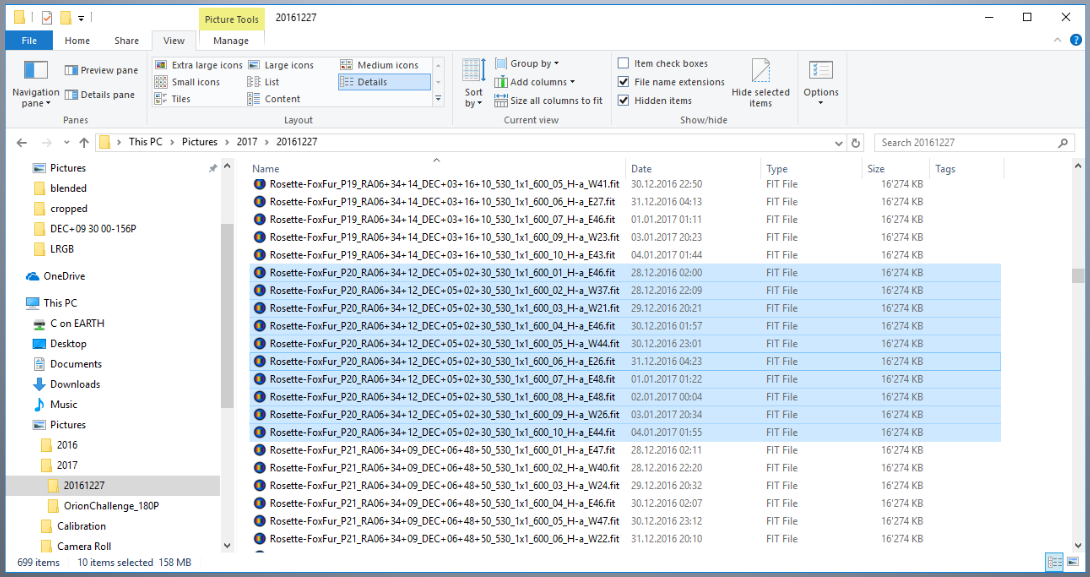
Creating wide-field mosaics

Preprocessing (Calibration)

- Once, the master dark and flat are generated they can be used for calibration

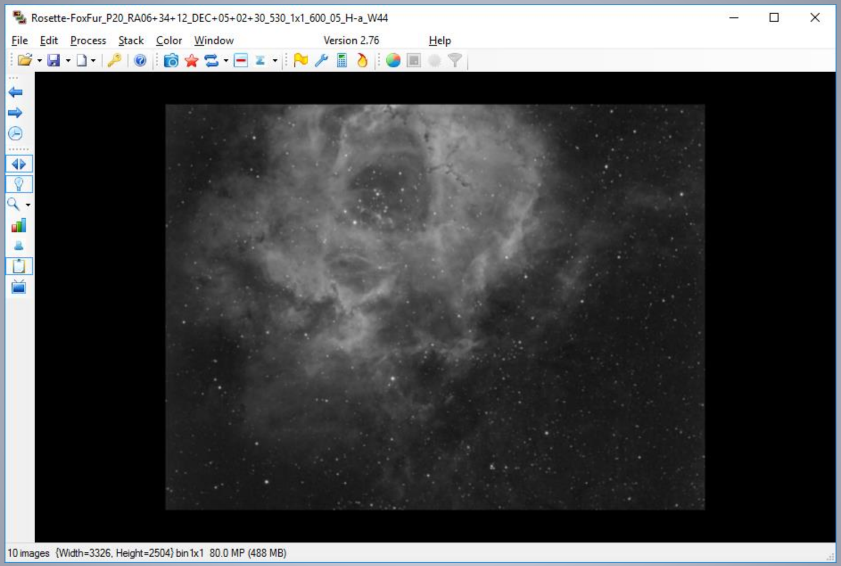
- To calibrate all frames of my mosaic projects, I follow the workflow described below:

- Open CCDStack
- Open Windows File Explorer
- Select the files that belongs to one tile

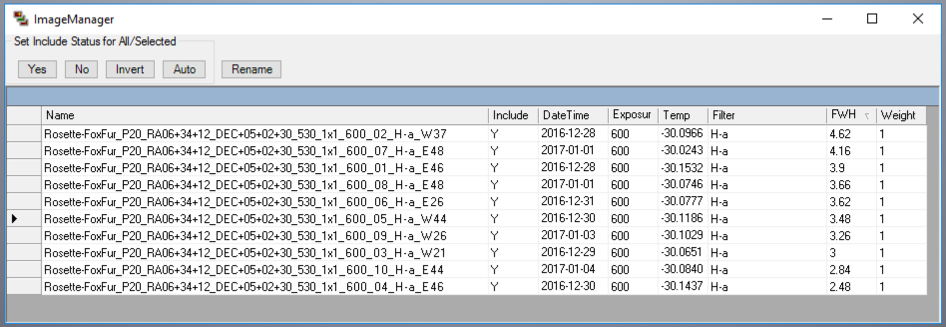


Creating wide-field mosaics
Preprocessing (Calibration)

- Drag & Drop the files into CCDStack



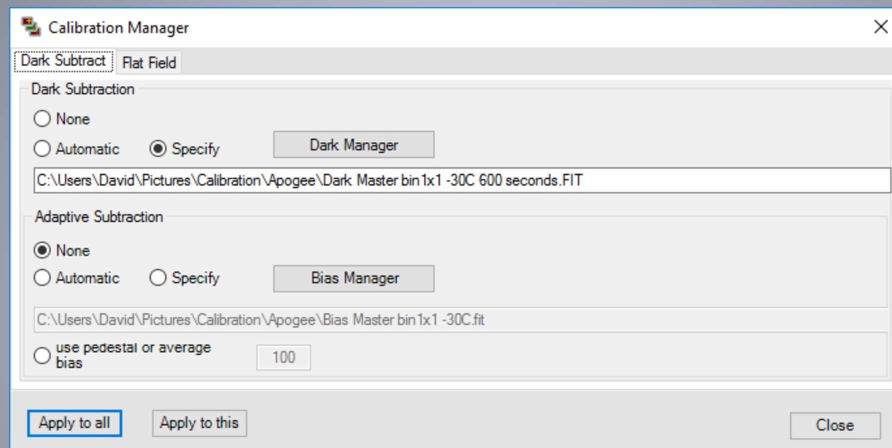
- Check if all selected files are listed in the image manager



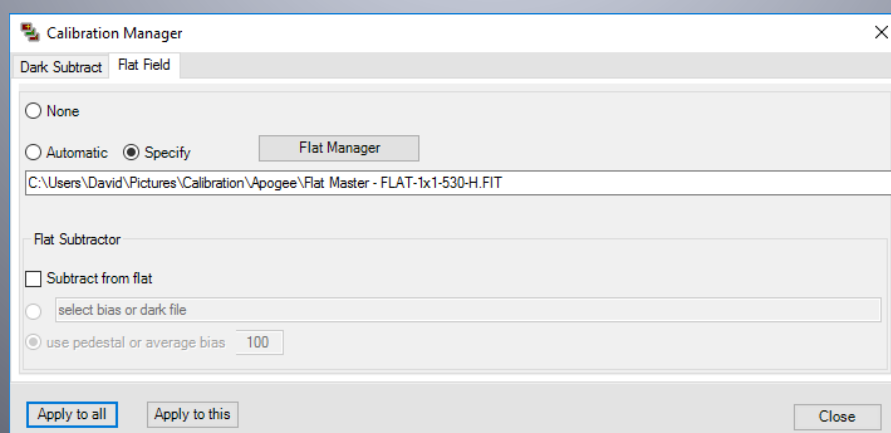
Name	Include	DateTime	Exposur	Temp	Filter	FWH	Weight
Rosette-FoxFur_P20_RA06+34+12_DEC+05+02+30_530_1x1_600_02_H-a_W37	Y	2016-12-28	600	-30.0966	H-a	4.62	1
Rosette-FoxFur_P20_RA06+34+12_DEC+05+02+30_530_1x1_600_07_H-a_E48	Y	2017-01-01	600	-30.0243	H-a	4.16	1
Rosette-FoxFur_P20_RA06+34+12_DEC+05+02+30_530_1x1_600_01_H-a_E46	Y	2016-12-28	600	-30.1532	H-a	3.9	1
Rosette-FoxFur_P20_RA06+34+12_DEC+05+02+30_530_1x1_600_08_H-a_E48	Y	2017-01-01	600	-30.0746	H-a	3.66	1
Rosette-FoxFur_P20_RA06+34+12_DEC+05+02+30_530_1x1_600_06_H-a_E26	Y	2016-12-31	600	-30.0777	H-a	3.62	1
Rosette-FoxFur_P20_RA06+34+12_DEC+05+02+30_530_1x1_600_05_H-a_W44	Y	2016-12-30	600	-30.1186	H-a	3.48	1
Rosette-FoxFur_P20_RA06+34+12_DEC+05+02+30_530_1x1_600_09_H-a_W26	Y	2017-01-03	600	-30.1029	H-a	3.26	1
Rosette-FoxFur_P20_RA06+34+12_DEC+05+02+30_530_1x1_600_03_H-a_W21	Y	2016-12-29	600	-30.0651	H-a	3	1
Rosette-FoxFur_P20_RA06+34+12_DEC+05+02+30_530_1x1_600_10_H-a_E44	Y	2017-01-04	600	-30.0840	H-a	2.84	1
Rosette-FoxFur_P20_RA06+34+12_DEC+05+02+30_530_1x1_600_04_H-a_E46	Y	2016-12-30	600	-30.1437	H-a	2.48	1

Creating wide-field mosaics
Preprocessing (Calibration)

- Open the calibration manager and specify the path to the file containing the dark master

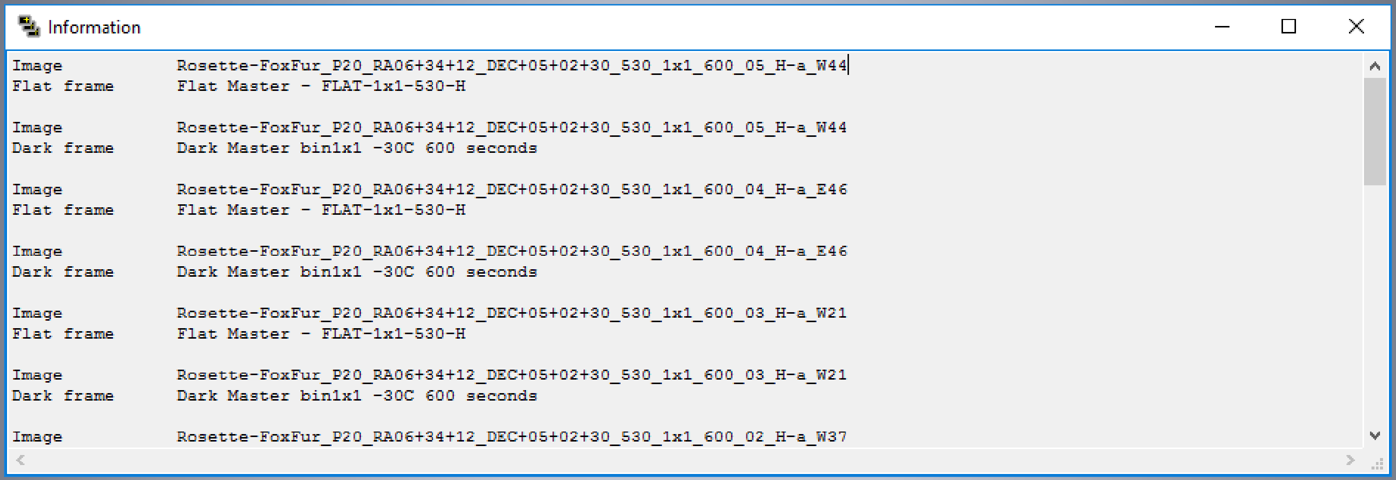


- Go to the flat field tab and specify the path to the file containing the flat master



Creating wide-field mosaics
Preprocessing (Calibration)

- Click on “Apply to all” to calibrate all loaded images



- Save all calibrated image to a folder for further use
  - Usually, I create a subfolder called “calibrated” in my project folder
  - I use this subfolder to store all images once they have been calibrated

- Continue to calibrate images of next tile until all tiles of the mosaic project have been calibrated

Flying bat and squid nebulae (12 panels mosaic)

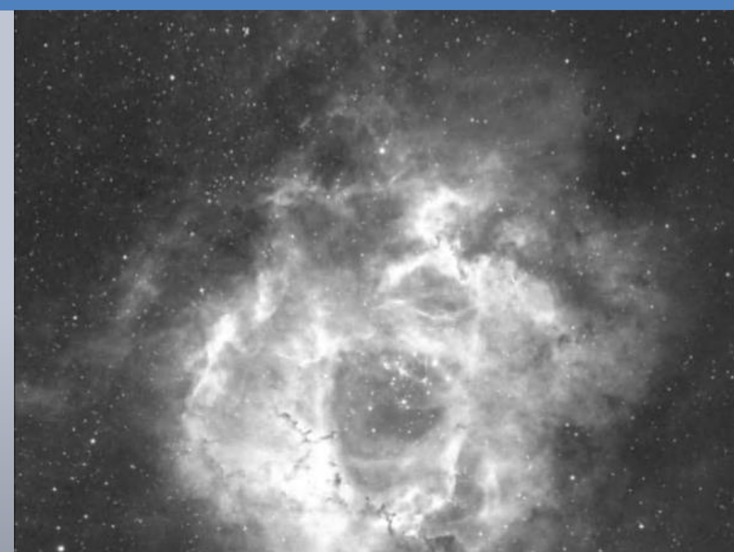
Chapter 5: Data quality evaluation

Creating wide-field mosaics
Data quality evaluation

- Once all monochromatic frames have been properly calibrated, all of them must be evaluated in term of quality
- This evaluation is very important because if the image stack contains one or several frames of poor quality, it will have a significant impact on the result
- Even if CCDStack provides powerful statistical data rejection algorithms that allow mixing frames of various qualities, the uses of frames with really poor quality provide a result worse than what we can get by simply excluding them from the stack
- That's why the data quality evaluation process is so important

Creating wide-field mosaics
Data quality evaluation

- With equatorial mount, the image is flipped on both axis (horizontal and vertical) when the mount is changing its pier side

Frame captured when mount pier is in west meridian	Frame captured when mount pier is in east meridian
	

- Before evaluating their quality, all the frames must have the same orientation

Creating wide-field mosaics

Data quality evaluation

- To do that, SkySurveyor provides a good help by adding in the image filename the pier side where the mount was when the frame was captured

```
Rosette-FoxFur_P20_RA06+34+12_DEC+05+02+30_530_1x1_600_01_H-a_E46.FIT
Rosette-FoxFur_P20_RA06+34+12_DEC+05+02+30_530_1x1_600_02_H-a_W37.FIT
Rosette-FoxFur_P20_RA06+34+12_DEC+05+02+30_530_1x1_600_03_H-a_W21.FIT
Rosette-FoxFur_P20_RA06+34+12_DEC+05+02+30_530_1x1_600_04_H-a_E46.FIT
Rosette-FoxFur_P20_RA06+34+12_DEC+05+02+30_530_1x1_600_05_H-a_W44.FIT
Rosette-FoxFur_P20_RA06+34+12_DEC+05+02+30_530_1x1_600_06_H-a_E26.FIT
Rosette-FoxFur_P20_RA06+34+12_DEC+05+02+30_530_1x1_600_07_H-a_E43.FIT
Rosette-FoxFur_P20_RA06+34+12_DEC+05+02+30_530_1x1_600_08_H-a_E43.FIT
Rosette-FoxFur_P20_RA06+34+12_DEC+05+02+30_530_1x1_600_09_H-a_W26.FIT
Rosette-FoxFur_P20_RA06+34+12_DEC+05+02+30_530_1x1_600_10_H-a_E44.FIT
```

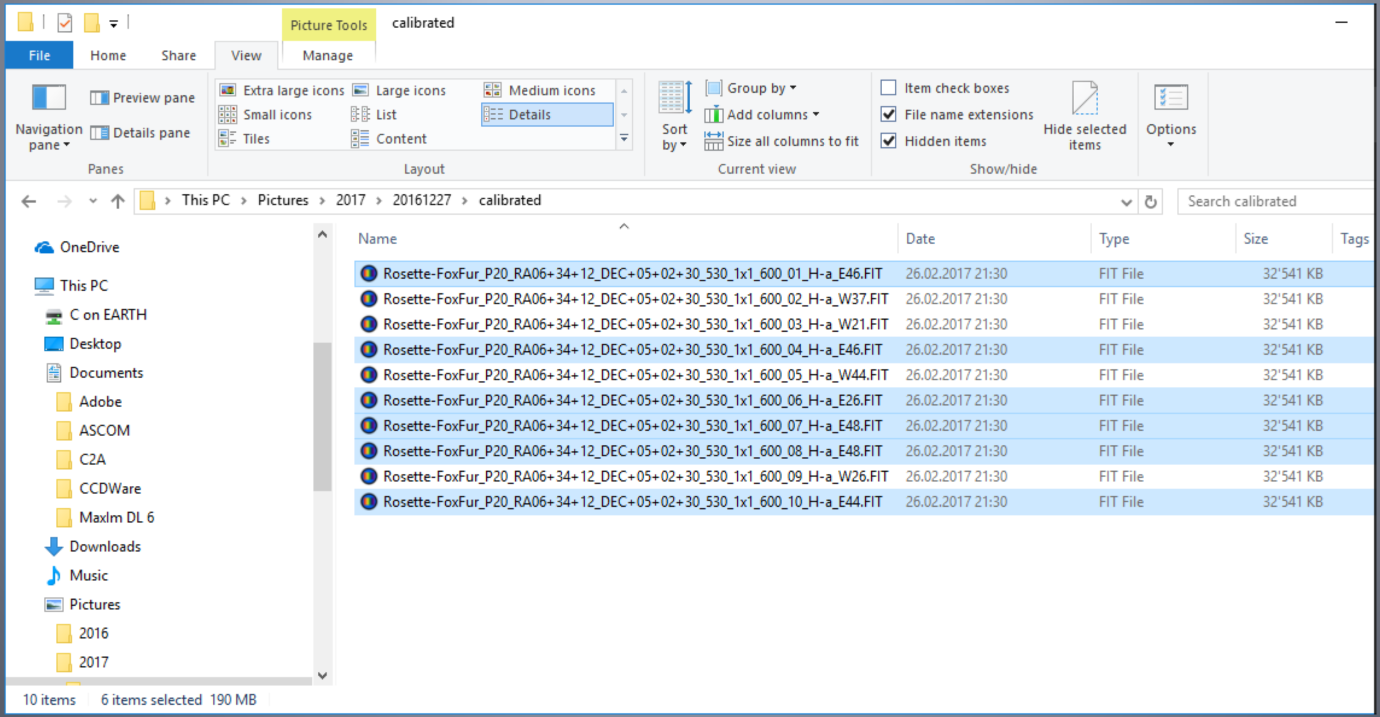
- To give the same orientation to all frames, the first step is to select a pier side East or West
- Once selected the same side must be used for all tiles of the mosaic project
- All frames of the opposite side must be flipped on both axis (horizontal and vertical)
- Usually, I use West orientation for all my frames but if the object is very high in altitude (close to the meridian) and if there is more East frames than West frames, the East orientation is preferred

Creating wide-field mosaics
Data quality evaluation

CEDIC

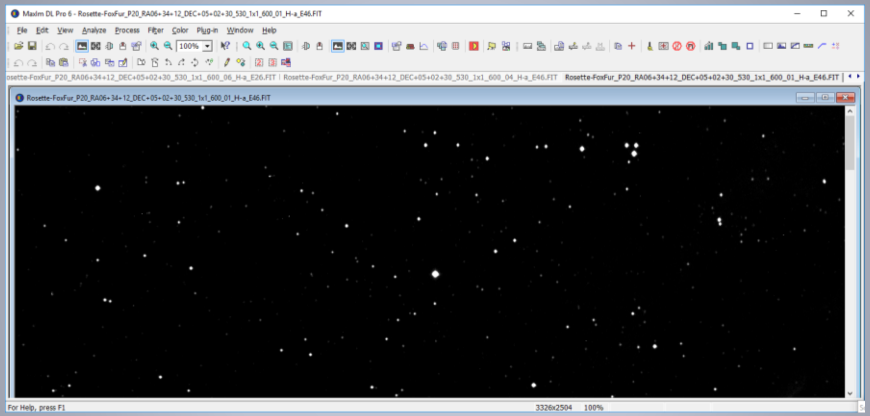
- To change the frames orientation, I use the following workflow:

- Open MaximDL
- Open Window File Explorer
- Select all files that must be flipped and mirrored

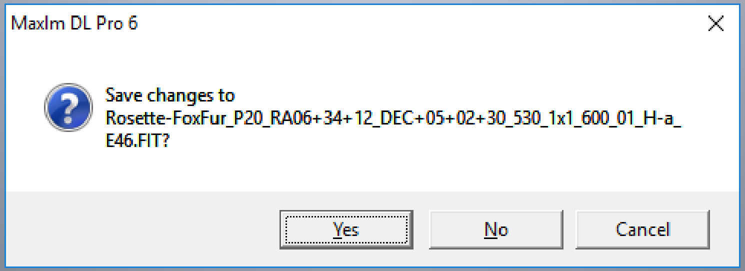


Creating wide-field mosaics
Data quality evaluation

- Drag & Drop the files to MaximDL
- Reverse the frame orientation with Edit->Flip and Edit->Mirror commands



- Click the close button



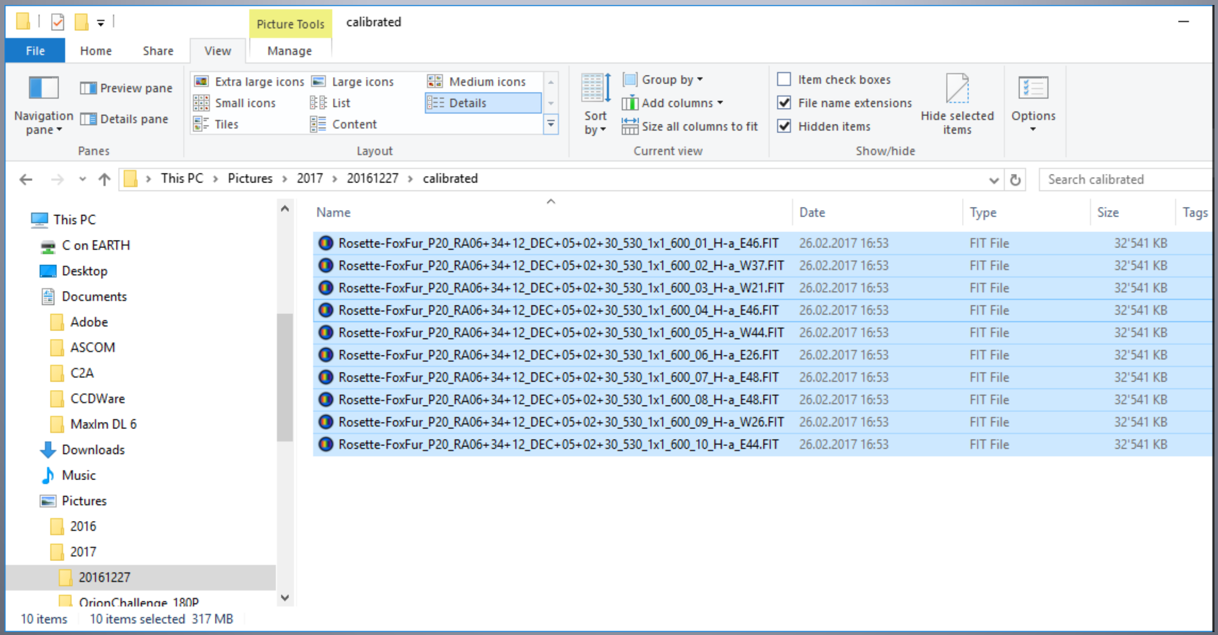
- Click Yes to save the image
- Continue to reverse the frames orientation until all have been processed

Creating wide-field mosaics

Data quality evaluation

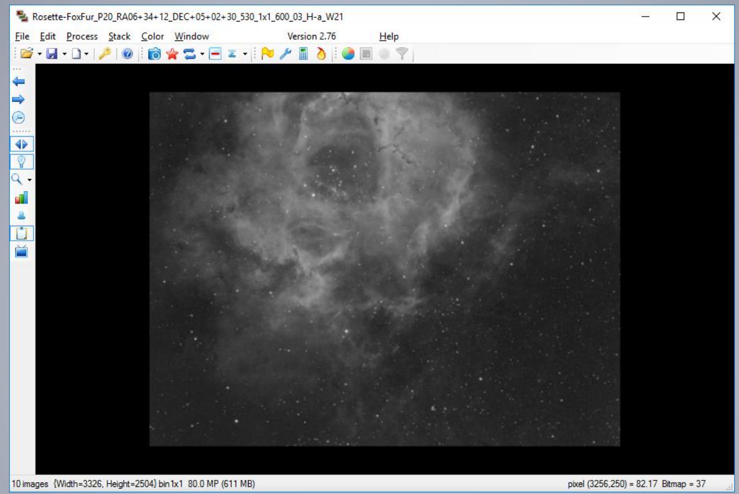
- To evaluate the quality of each individual frame by following the workflow described below:

- Open CCDStack
- Open Windows File Explorer
- Select the files that belongs to one tile

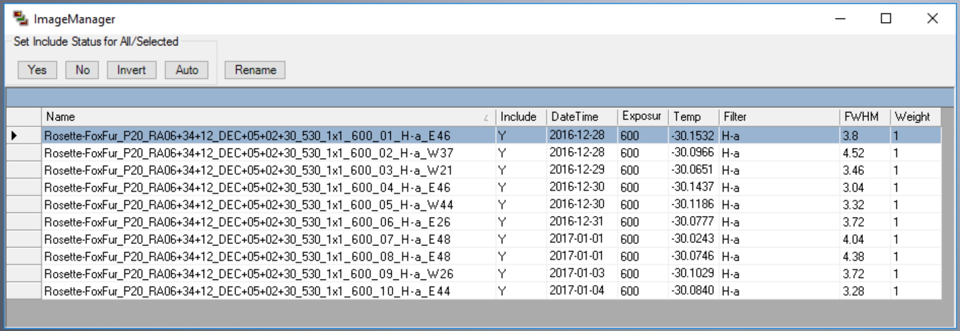


Creating wide-field mosaics
Data quality evaluation

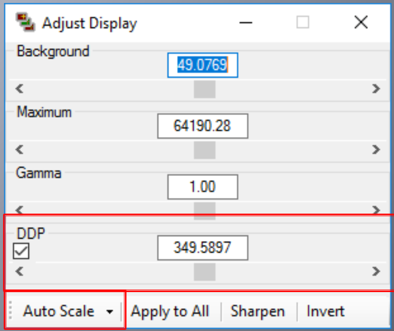
- Drag & Drop the files into CCDStack



- Check if all selected files are listed in the image manager



Name	Include	DateTime	Exposur	Temp	Filter	FWHM	Weight
Rosette-FoxFur_P20_RA06+34+12_DEC+05+02+30_530_1x1_600_01_H-a_E46	Y	2016-12-28	600	-30.1532	H-a	3.8	1
Rosette-FoxFur_P20_RA06+34+12_DEC+05+02+30_530_1x1_600_02_H-a_W37	Y	2016-12-28	600	-30.0966	H-a	4.52	1
Rosette-FoxFur_P20_RA06+34+12_DEC+05+02+30_530_1x1_600_03_H-a_W21	Y	2016-12-29	600	-30.0651	H-a	3.46	1
Rosette-FoxFur_P20_RA06+34+12_DEC+05+02+30_530_1x1_600_04_H-a_E46	Y	2016-12-30	600	-30.1437	H-a	3.04	1
Rosette-FoxFur_P20_RA06+34+12_DEC+05+02+30_530_1x1_600_05_H-a_W44	Y	2016-12-30	600	-30.1186	H-a	3.32	1
Rosette-FoxFur_P20_RA06+34+12_DEC+05+02+30_530_1x1_600_06_H-a_E26	Y	2016-12-31	600	-30.0777	H-a	3.72	1
Rosette-FoxFur_P20_RA06+34+12_DEC+05+02+30_530_1x1_600_07_H-a_E48	Y	2017-01-01	600	-30.0243	H-a	4.04	1
Rosette-FoxFur_P20_RA06+34+12_DEC+05+02+30_530_1x1_600_08_H-a_E48	Y	2017-01-01	600	-30.0746	H-a	4.38	1
Rosette-FoxFur_P20_RA06+34+12_DEC+05+02+30_530_1x1_600_09_H-a_W26	Y	2017-01-03	600	-30.1029	H-a	3.72	1
Rosette-FoxFur_P20_RA06+34+12_DEC+05+02+30_530_1x1_600_10_H-a_E44	Y	2017-01-04	600	-30.0840	H-a	3.28	1

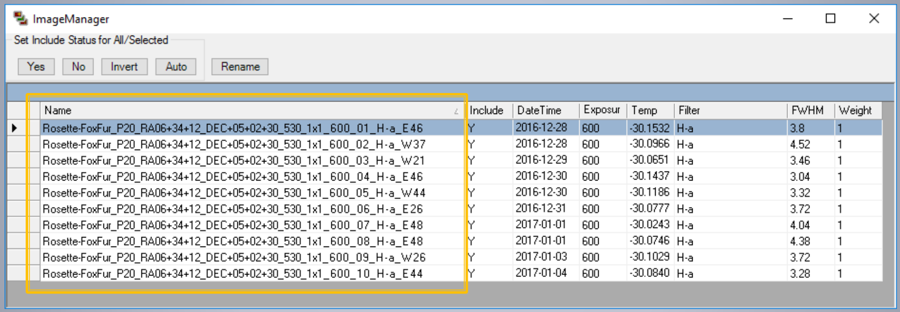


- Activate the DDP, and click auto scale in order to see all details in frames

Creating wide-field mosaics

Data quality evaluation

- To make the first visual evaluation of all frames the list must be sorted from the lowest frame number to the highest frame number
- To do that, simply click the Name column

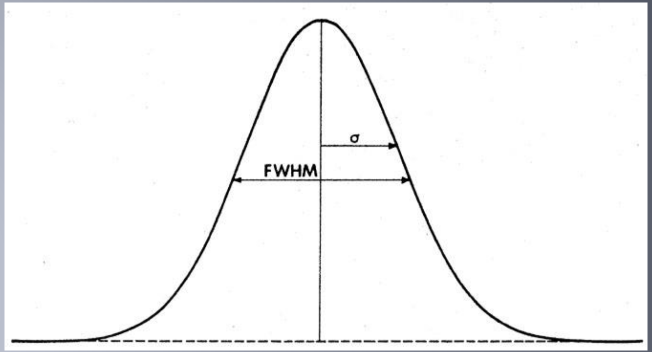


Name	Include	DateTime	Exposur	Temp	Filter	FWHM	Weight
Rosette-FoxFur_P20_RA06+34+12_DEC+05+02+30_530_1x1_600_01_H-a_E46	Y	2016-12-28	600	-30.1532	H-a	3.8	1
Rosette-FoxFur_P20_RA06+34+12_DEC+05+02+30_530_1x1_600_02_H-a_W37	Y	2016-12-28	600	-30.0966	H-a	4.52	1
Rosette-FoxFur_P20_RA06+34+12_DEC+05+02+30_530_1x1_600_03_H-a_W21	Y	2016-12-29	600	-30.0651	H-a	3.46	1
Rosette-FoxFur_P20_RA06+34+12_DEC+05+02+30_530_1x1_600_04_H-a_E46	Y	2016-12-30	600	-30.1437	H-a	3.04	1
Rosette-FoxFur_P20_RA06+34+12_DEC+05+02+30_530_1x1_600_05_H-a_W44	Y	2016-12-30	600	-30.1186	H-a	3.32	1
Rosette-FoxFur_P20_RA06+34+12_DEC+05+02+30_530_1x1_600_06_H-a_E26	Y	2016-12-31	600	-30.0777	H-a	3.72	1
Rosette-FoxFur_P20_RA06+34+12_DEC+05+02+30_530_1x1_600_07_H-a_E48	Y	2017-01-01	600	-30.0243	H-a	4.04	1
Rosette-FoxFur_P20_RA06+34+12_DEC+05+02+30_530_1x1_600_08_H-a_E48	Y	2017-01-01	600	-30.0746	H-a	4.38	1
Rosette-FoxFur_P20_RA06+34+12_DEC+05+02+30_530_1x1_600_09_H-a_W26	Y	2017-01-03	600	-30.1029	H-a	3.72	1
Rosette-FoxFur_P20_RA06+34+12_DEC+05+02+30_530_1x1_600_10_H-a_E44	Y	2017-01-04	600	-30.0840	H-a	3.28	1

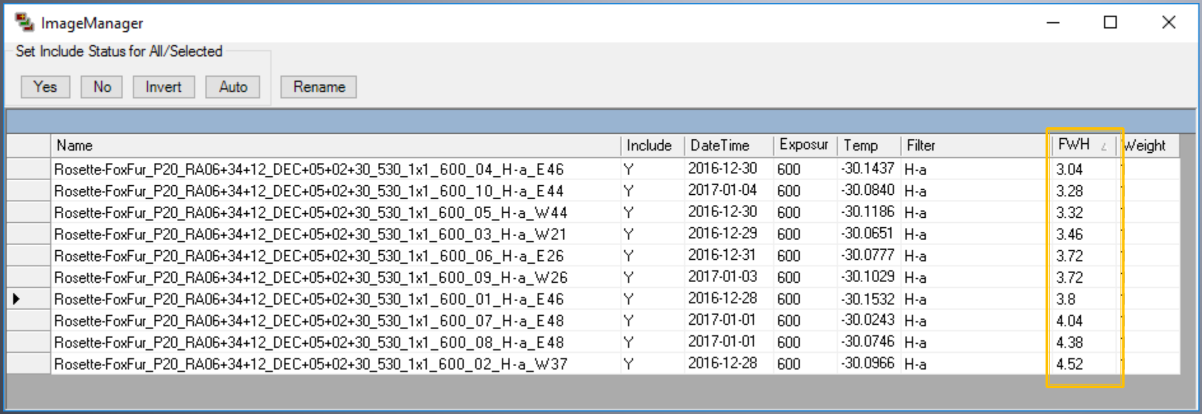
- To inspect each frame step by step, click the first frame and go across the list by pressing the down arrow on the keyboard
- The correct orientation and the overall quality (contrast and background level) is evaluated visually by comparing each frame with at least one other having a better visual aspect
- During this visual inspection, if at least one bad frame is found, then the bad frames must be removed from the list and if a frame is not correctly oriented it must be reoriented before continuing the evaluation procedure

Creating wide-field mosaics
Data quality evaluation

- Its time to evaluate the quality of each frame by their FWHM value
- The point – spread function (PSF) is the result of blurring a point-source
- As FWHM is a constant measure of the PSF and the resolution regardless of intensity, it provide a good indicator about the quality of a frame
- To do that evaluation the list must be sorted from the lowest to the highest FWHM value
- To do that, simply click the FWHM column



Full Width at Half Maximum (FWHM) is constant regardless of star brightness



ImageManager

Set Include Status for All/Selected

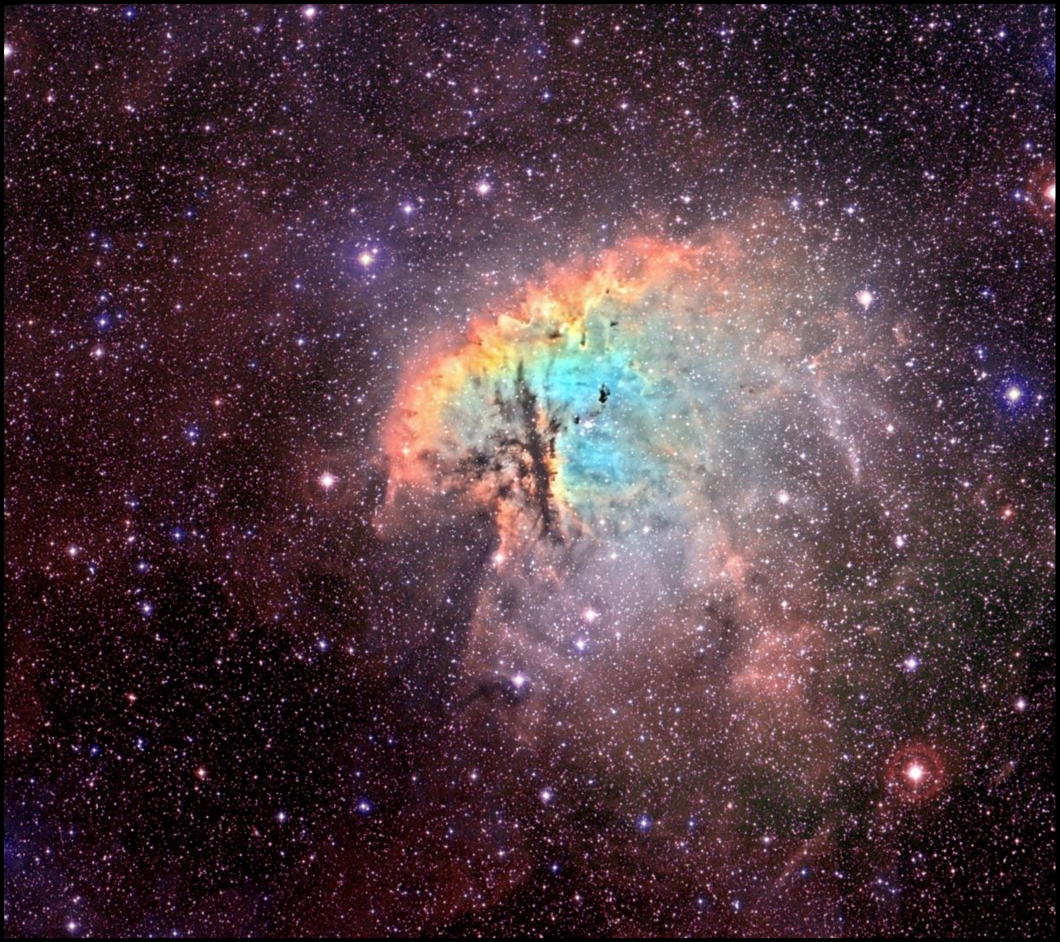
Yes | No | Invert | Auto | Rename

Name	Include	DateTime	Exposur	Temp	Filter	FWH	Weight
Rosette-FoxFur_P20_RA06+34+12_DEC+05+02+30_530_1x1_600_04_H-a_E46	Y	2016-12-30	600	-30.1437	H-a	3.04	
Rosette-FoxFur_P20_RA06+34+12_DEC+05+02+30_530_1x1_600_10_H-a_E44	Y	2017-01-04	600	-30.0840	H-a	3.28	
Rosette-FoxFur_P20_RA06+34+12_DEC+05+02+30_530_1x1_600_05_H-a_W44	Y	2016-12-30	600	-30.1186	H-a	3.32	
Rosette-FoxFur_P20_RA06+34+12_DEC+05+02+30_530_1x1_600_03_H-a_W21	Y	2016-12-29	600	-30.0651	H-a	3.46	
Rosette-FoxFur_P20_RA06+34+12_DEC+05+02+30_530_1x1_600_06_H-a_E26	Y	2016-12-31	600	-30.0777	H-a	3.72	
Rosette-FoxFur_P20_RA06+34+12_DEC+05+02+30_530_1x1_600_09_H-a_W26	Y	2017-01-03	600	-30.1029	H-a	3.72	
Rosette-FoxFur_P20_RA06+34+12_DEC+05+02+30_530_1x1_600_01_H-a_E46	Y	2016-12-28	600	-30.1532	H-a	3.8	
Rosette-FoxFur_P20_RA06+34+12_DEC+05+02+30_530_1x1_600_07_H-a_E48	Y	2017-01-01	600	-30.0243	H-a	4.04	
Rosette-FoxFur_P20_RA06+34+12_DEC+05+02+30_530_1x1_600_08_H-a_E48	Y	2017-01-01	600	-30.0746	H-a	4.38	
Rosette-FoxFur_P20_RA06+34+12_DEC+05+02+30_530_1x1_600_02_H-a_W37	Y	2016-12-28	600	-30.0966	H-a	4.52	

Creating wide-field mosaics
Data quality evaluation

- Usually, I reject all frames having FWHM above 5 and keep only frames with FWHM above 4 after visual inspection and comparison

- At the end of the evaluation process, all the rejected frames must be deleted from the folder to keep only the calibrated frames that reach the expected quality level
  - Remember which frame as the best quality to be able to quickly reuse it during alignment process



PacMan nebula

Chapter 6: Registration (alignment)

Creating wide-field mosaics
Registration (alignment)

- The goal of registration is to align each frame on the same reference in order to be able to combine the signal of individual exposure into a single master frame
- To be correctly combined (stacked) the centroids of all stars must be exactly aligned at a subpixel level with their counterparts among all frames
- There are several reasons why stars become misaligned between frames:
  - The data was taken on different nights
  - The data was taken from different mount pier side
  - The equatorial mount is not perfectly aligned to the celestial pole
  - There is optical distortion caused by the atmospheric turbulences
  - There are mechanical flexions on the optical train
  - There are guiding and tracking errors
  - The data was acquired by various optical system and/or sensors
  - There is a natural drift between exposure
  - There is a forced pixel drift between exposure (i.e. Dithering)
  - The data was taken at difference focal length with different binning mode

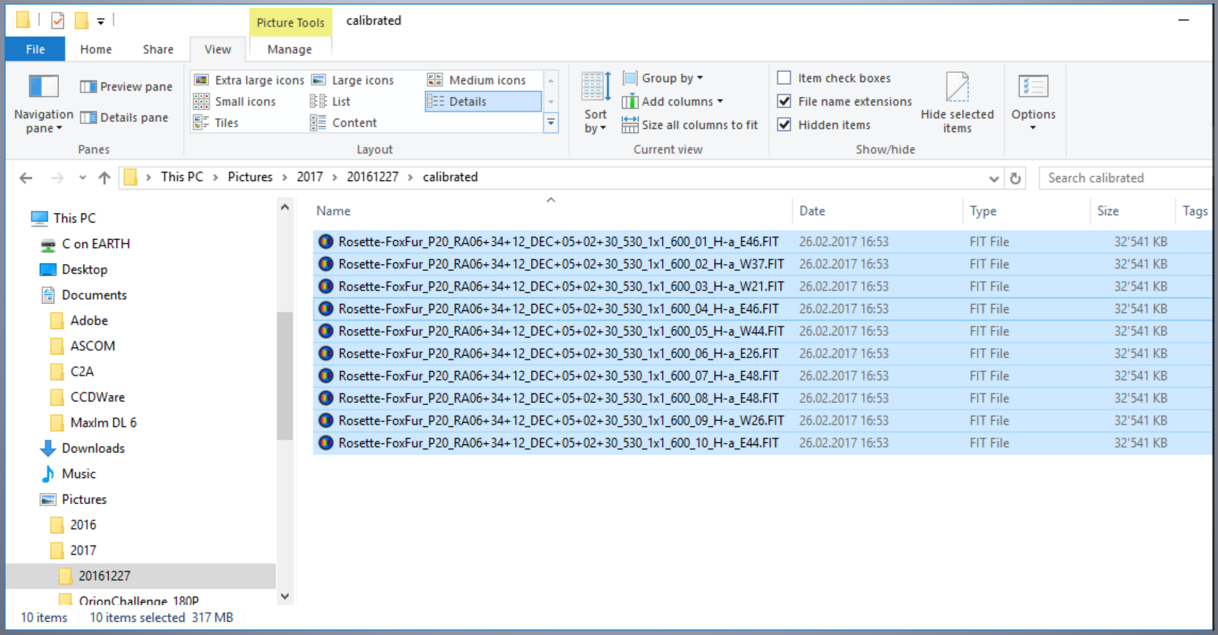
Creating wide-field mosaics
Registration (alignment)

- To achieve a correct alignment in all cases the frames must be offset, rotated, scaled and stretched
- If the frames are not correctly aligned the same objects will appear twice or multiple times on the master frame
- CCDStack contains a wide variety of alignment algorithms that can be used to make good alignment in all case of figure
- Usually, for deep sky imaging, I use CCDIS which allow aligning frames by finding and matching star patterns among the frame collection or Star Match that works well on frames captured with the same scale
- The challenge is to find a resampling algorithm that will have a minimum impact on the data during the alignment process
- As a best practice recommended by Adam Block in the book (Lessons from the Masters - Robert Gendler), I use the algorithm called Nearest Neighbor
- This algorithm only shifts frames to the nearest pixel and does not generate new pixels by interpolation

Creating wide-field mosaics
Registration (alignment)

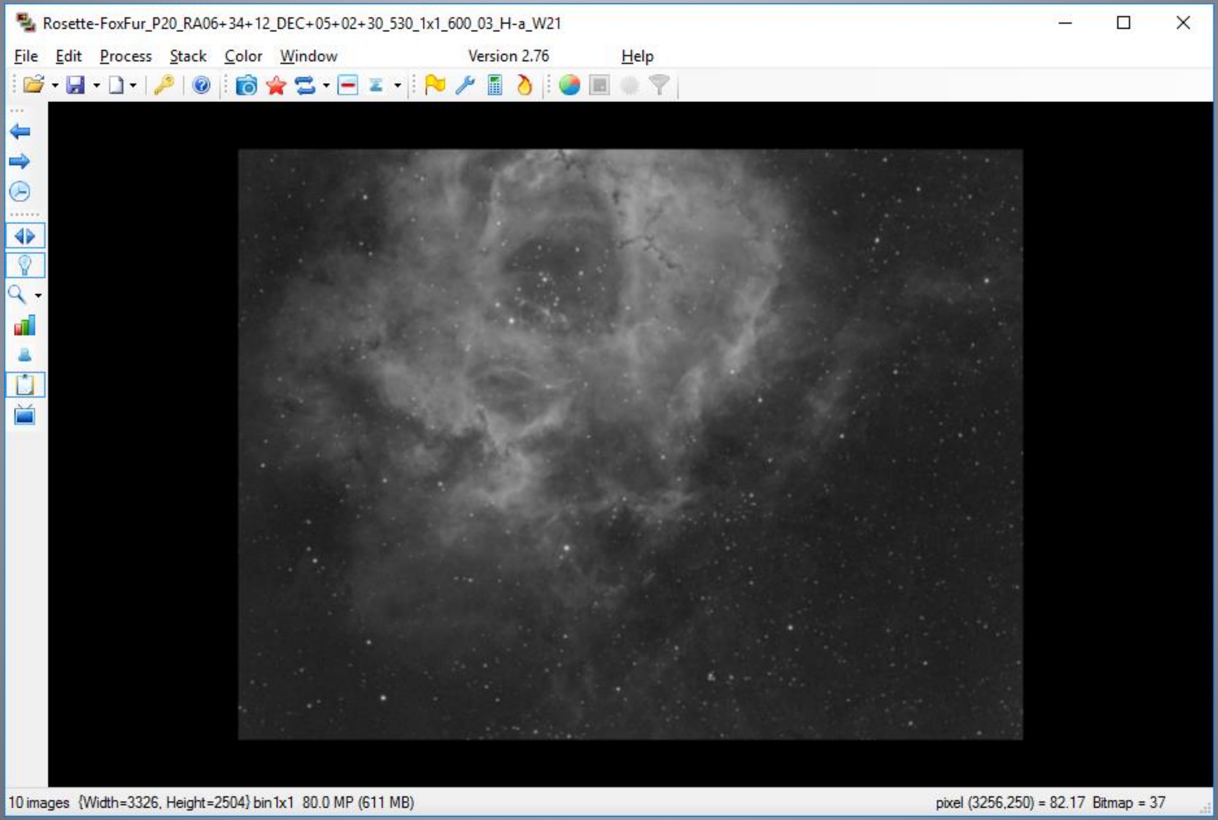
- To align the frames, I use the following workflow:

- Open CCDStack
- Open Windows File Explorer
- Select the files that belongs to one tile



Creating wide-field mosaics
Registration (alignment)

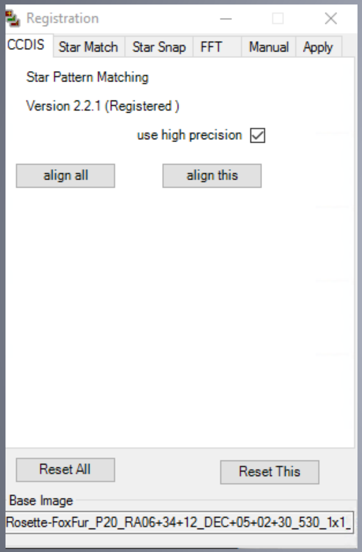
- Drag & Drop the files into CCDStack



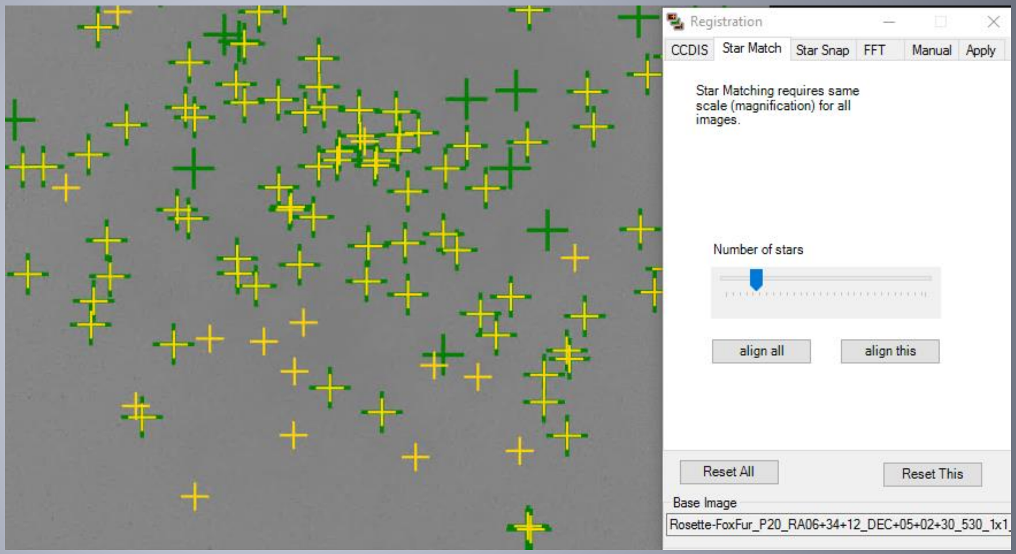
- Select the frame having the best quality to use it as reference image for the alignment
- Click on the menu Stack->Register

Creating wide-field mosaics
Registration (alignment)

- Choose CCDIS or Star Match tab



CCDIS



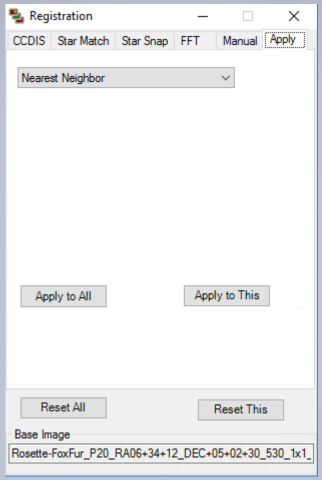
Star Match

- In CCDIS to make subpixel alignment always activate the high precision option
- Click “align all” button

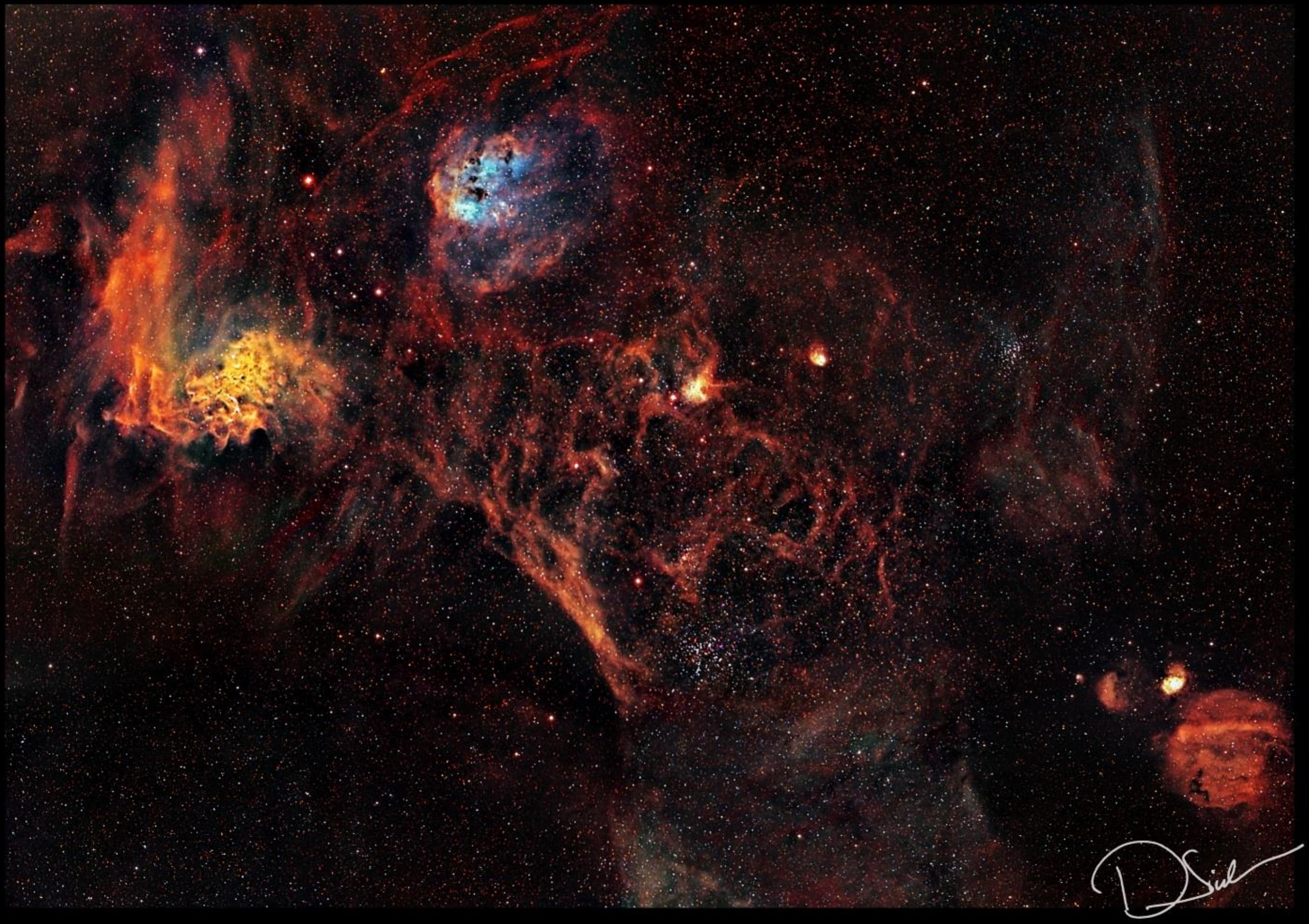
Creating wide-field mosaics

Registration (alignment)

- Once they are all aligned, click on the “Apply tab”



- Choose “Nearest Neighbor” and click on “Apply to All” button
- To check the correct alignment, I usually step through all frames
  - If they are perfectly aligned there is no move between each frame
- Save all registered images to a folder for further use
  - Usually, I create a subfolder called “registered” in my project folder
  - I use this subfolder to store all images once they have been registered



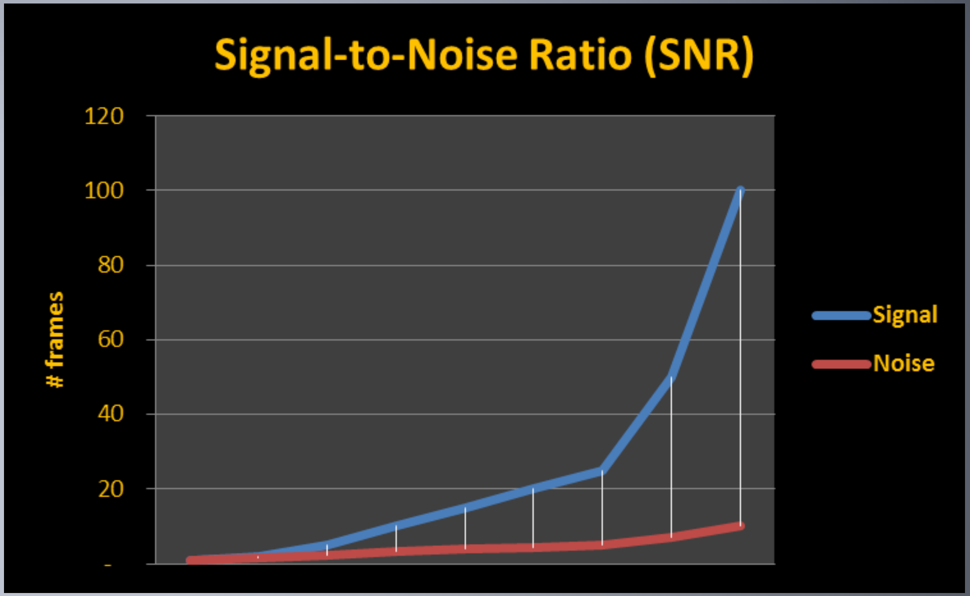
Tadpole and flamming star nebulae (20 panels mosaic)

Chapter 7: Data rejection and stacking

- Image stacking is a very powerful method that increases the signal-to-noise ratio and that increases the dynamic range of master light frame
- The effect of image stacking seems almost magical when we compares the signal of a single light frame and all information and details that are visible on the resulting master frame
- There is no magic behind the image stacking and the real explanation are easy to understand

Creating wide-field mosaics
Data rejection and stacking

- When the signal (photons emitted by a light source) are summed the relative noise is equal to the square root of the accumulated signal
  - The difference between the amount of signal and the amount of noise is caused by the random nature of the noise
- As we can see in this graph, the signal is growing exponentially and the associated noise remains almost flat, this is why the effect of the stacking seems magical
- In regard of this, we see that the best number of frame for an image stack is somewhere between 10 and 40 frames
  - Below 10 the SNR is poor and above 40 the required capture time become inefficient

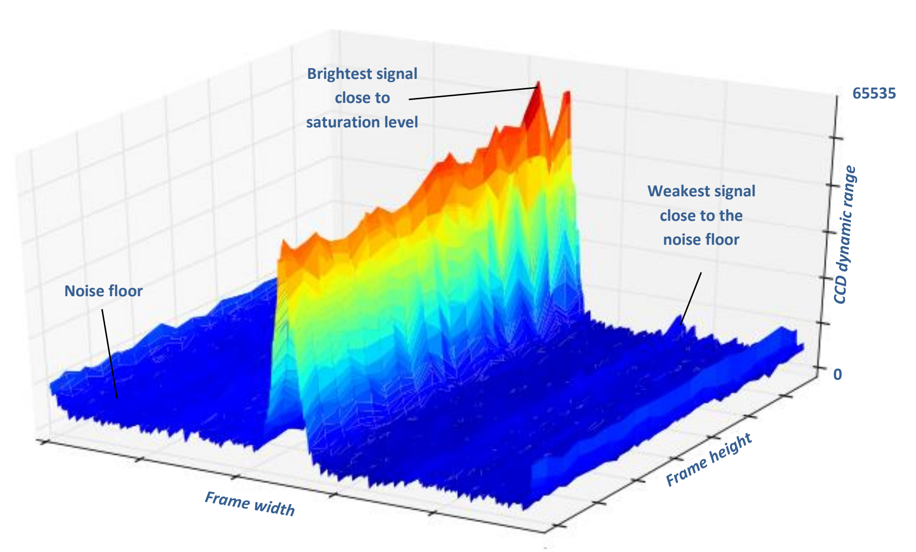


Creating wide-field mosaics
Data rejection and stacking

- Another benefit provided by the image stacking is that it increase the dynamic range of the image
- Dynamic Range is the ratio between the brightest possible recordable value and the dimmest possible recorded value
- CCD sensor measures the light at each pixel by counting the photons that fall into a well (photosite)
- The deepness of the well (photosite) determines the dynamic range of a camera
- When a photosite receive more photons than what it can contains the pixel is saturated
- When a photosite receive few photons the well remain almost empty and close to the noise floor
- So, every experienced astrophotographers know that their challenge is to find a good balance between the faint and brightest light sources that are present in a frame
- If the frame integration time is too short, the faint light source will be destructed by the readout noise and in the other hand if the frame integration time is too long, the brightest light sources will be saturated
- The solution is to find an integration time that is not too short and not too long

Creating wide-field mosaics
Data rejection and stacking

- How the stacking increase the dynamic range?
- Usually, sensors used for deep sky imaging are able to record signal on 16bit counters
- This allows a dynamic range between 1 to 64 killo shades
- The stacking algorithms are able to sum and record the signal on 32bit or 64bit counters
- This allows a dynamic range between 1 to 4.2 billion of shades for 32bit (single precision) and 1 to 184 billion of billions of shades for 64bit (double precision)



3D plot of a single light frame that shows the signal colored in red and green hues and the noise floor colored in dark blue

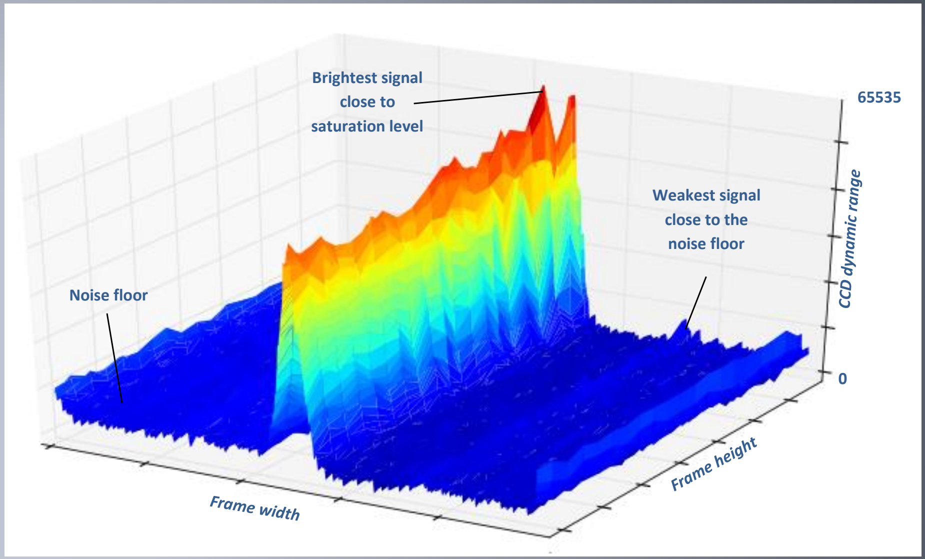
Creating wide-field mosaics
Data rejection and stacking

- However, when stacking, the dimmest parts accumulate into higher values that escape the floor of the dynamic range, while simultaneously increasing the dynamic range as the brightest parts get brighter and brighter as more images are added to the stack

- So, the use of larger dynamic range at stacking allows avoiding saturation of the brightest parts

- The main advantage of increasing the dynamic range is that it provides more flexibility for image processing
  - it becomes possible to stretch the image without increasing the background noise

- This becomes possible because increasing the dynamic range also increase the gap between the weakest signal and the noise floor



3D plot of a single light frame that shows the signal colored in red and green hues and the noise floor colored in dark blue

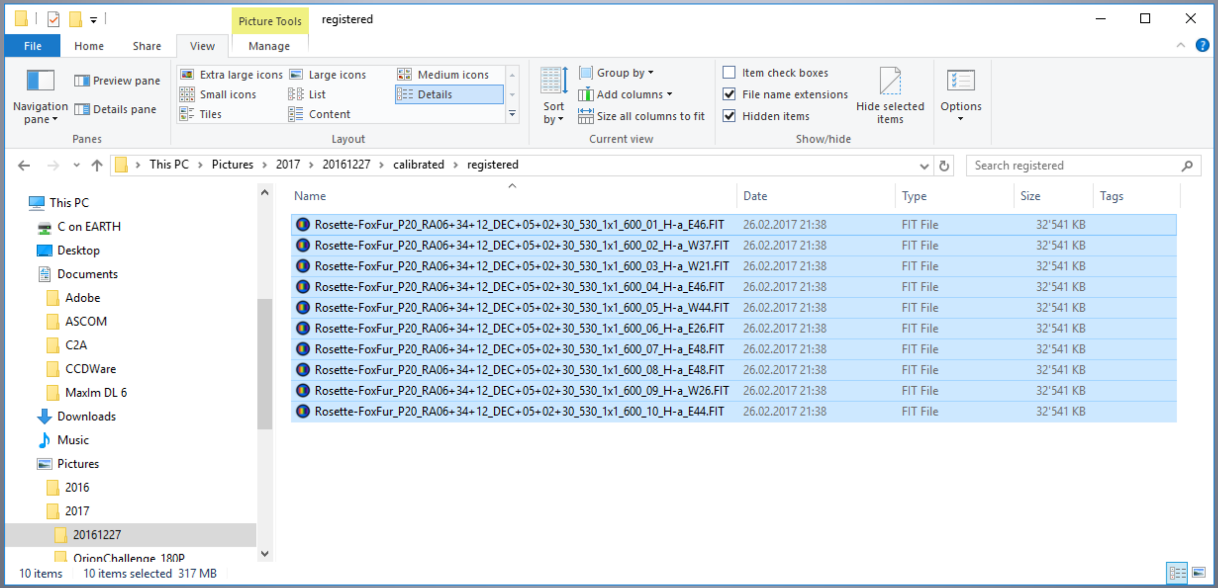
Creating wide-field mosaics
Data rejection and stacking

- The main drawback of the stacking is that the imperfections that can exist on each frames are also stacked and this will affect the quality of the overall image
- To avoid that, CCDStack® offers powerful statistical data rejection algorithms that allow excluding imperfections that can exist on individual frames
- Due to the variation of the seeing, the strength of the signal recorded on each frame is not constant along time
- To equalize the variation of the signal level of each frame, we must normalize them
- Normalizing a frame means that a multiplication factor (weight) is applied to every frame in order to increase/decrease the signal
- The weight of each frame is calculated by comparing each frame with a reference frame

Creating wide-field mosaics
Data rejection and stacking

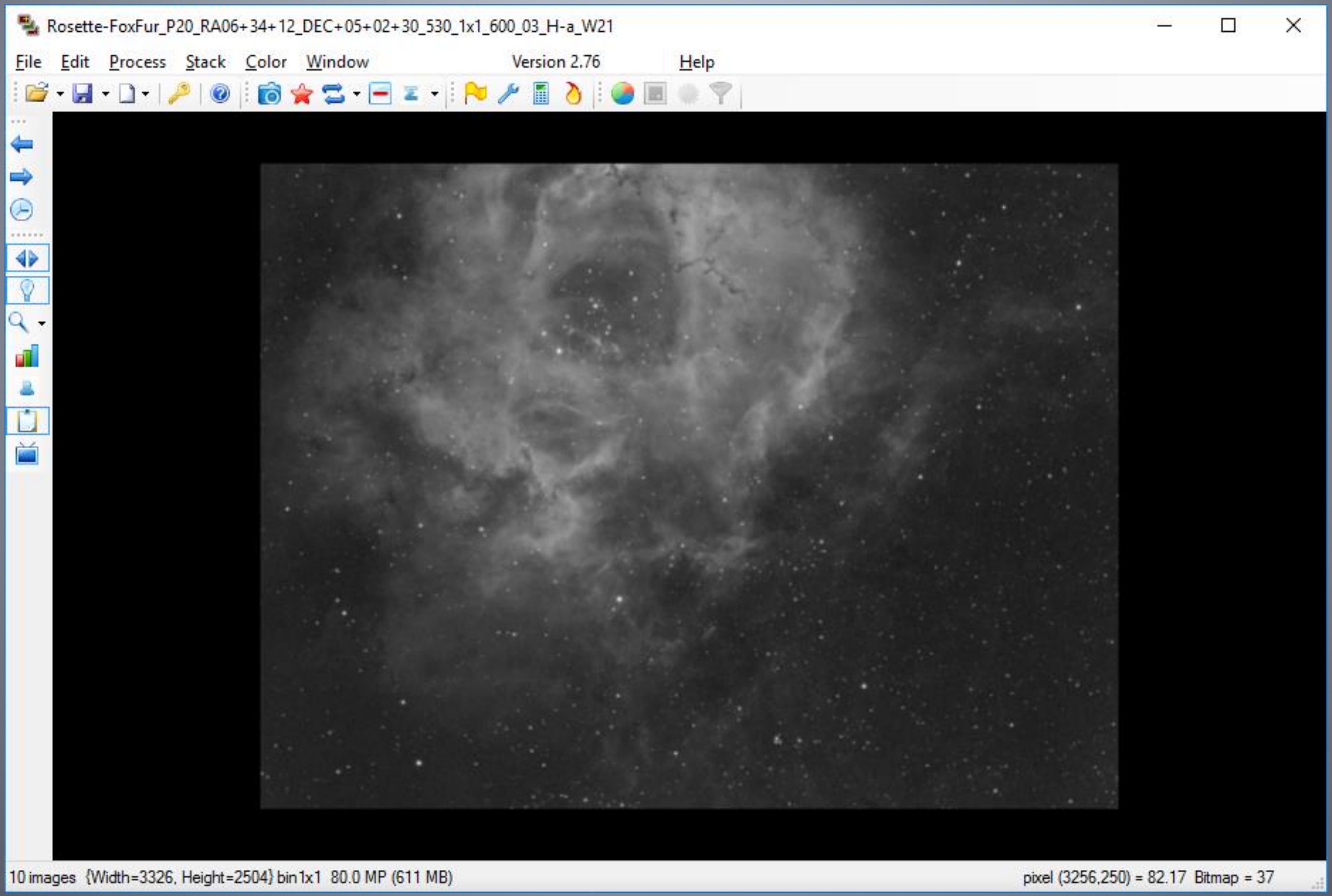
- To stack the frames, I use the following workflow

- Open CCDStack
- Open Windows File Explorer
- Select the files that belongs to one tile



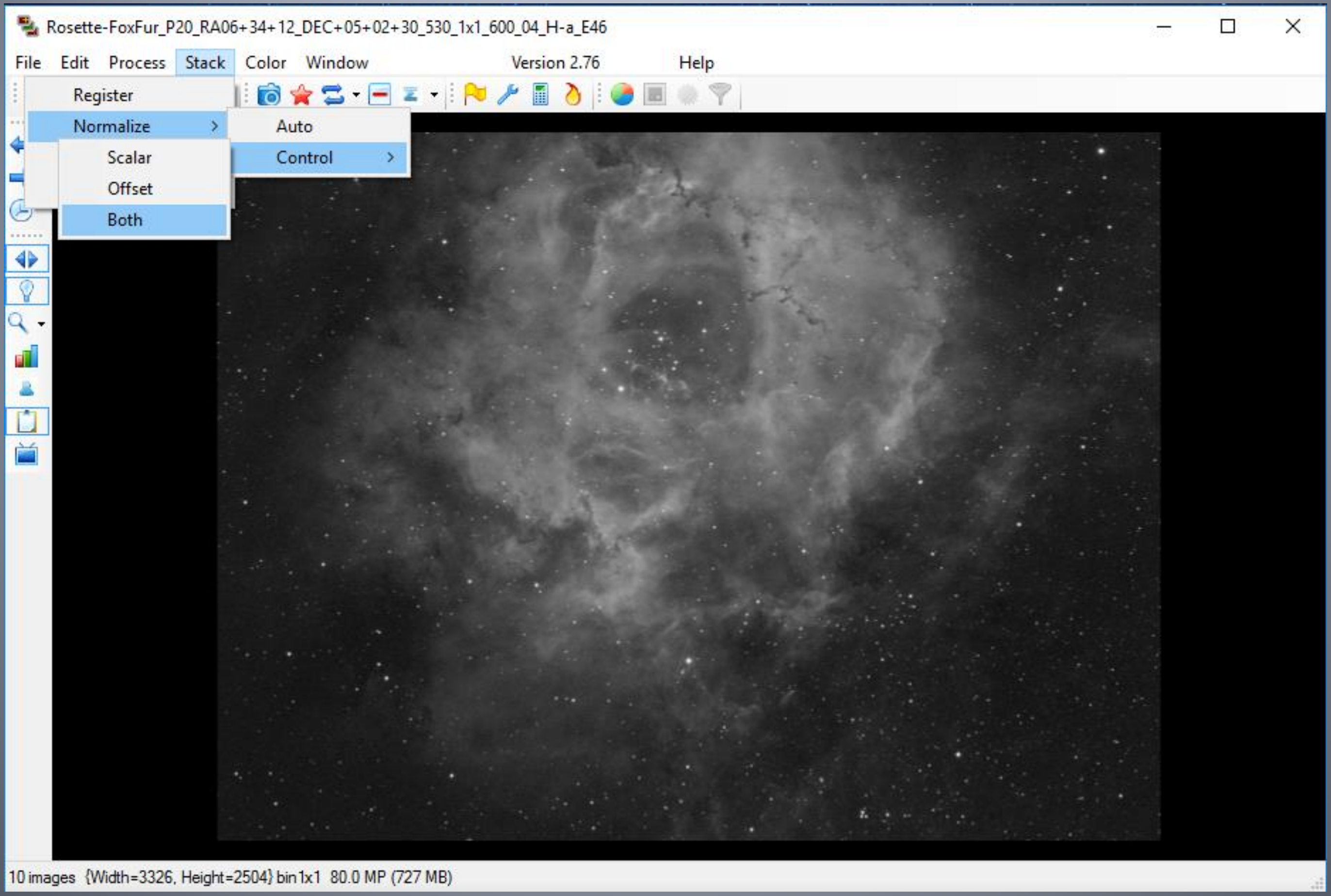
Creating wide-field mosaics
Data rejection and stacking

- Drag & Drop the files into CCDStack



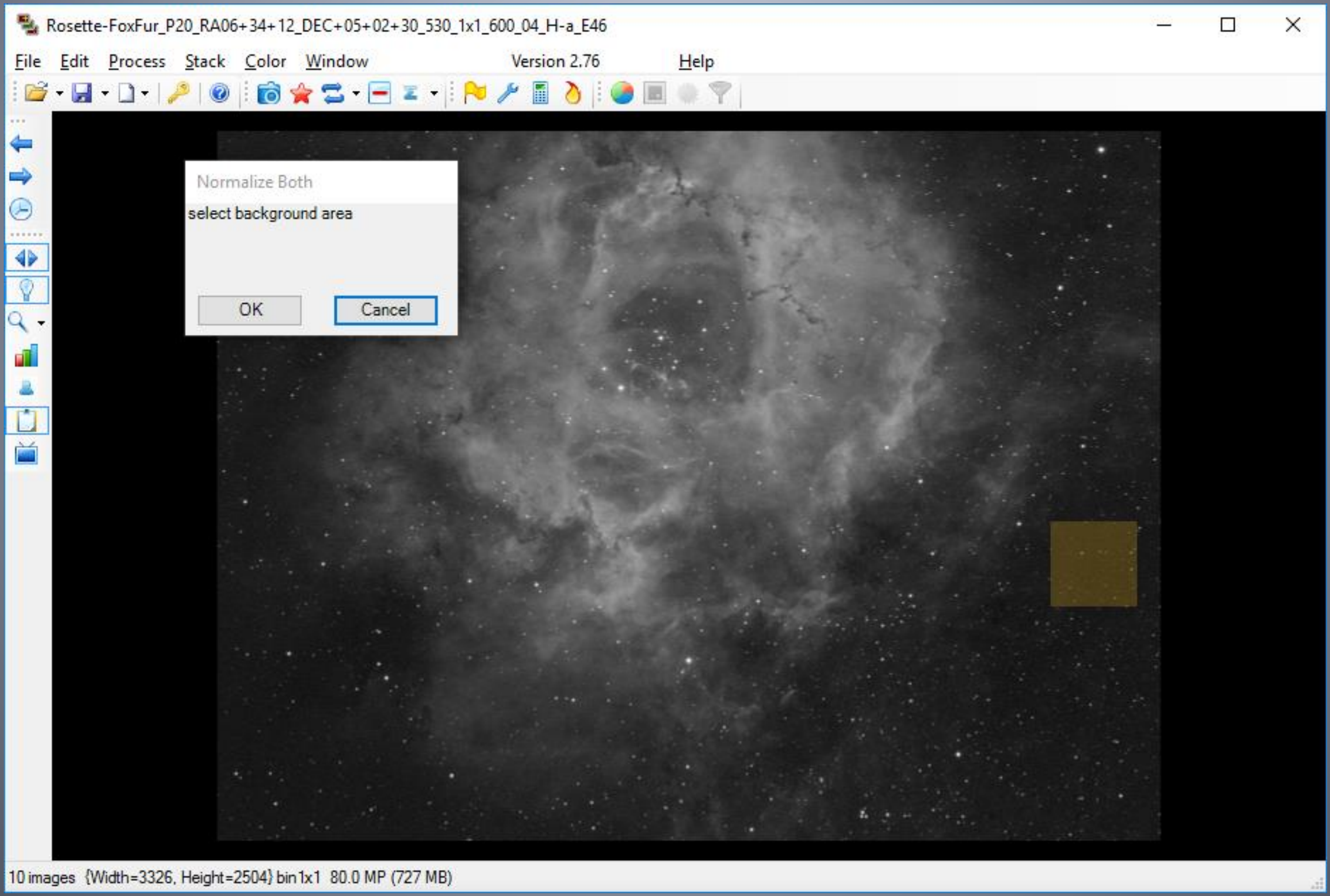
Creating wide-field mosaics
Data rejection and stacking

- Select the frame having the best quality to use it as reference image for normalization
- Click on the menu Stack->Normalize->Control->Both



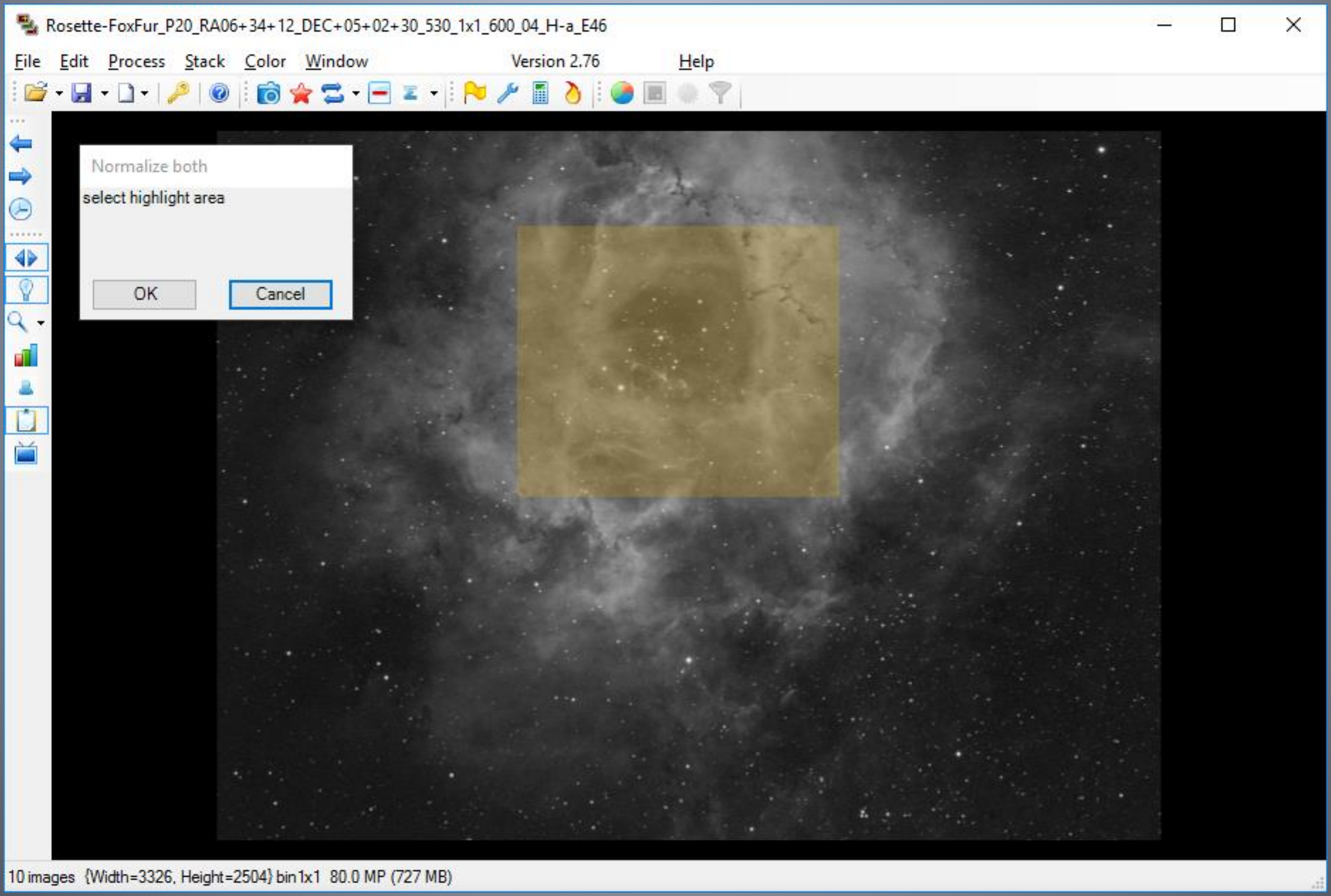
Creating wide-field mosaics
Data rejection and stacking

- Select background area and click OK to validate



Creating wide-field mosaics
Data rejection and stacking

- Select highlight area and click OK to validate



Creating wide-field mosaics

Data rejection and stacking

CEDIC

- The calculated weight of each frame is displayed in the image manager

ImageManager

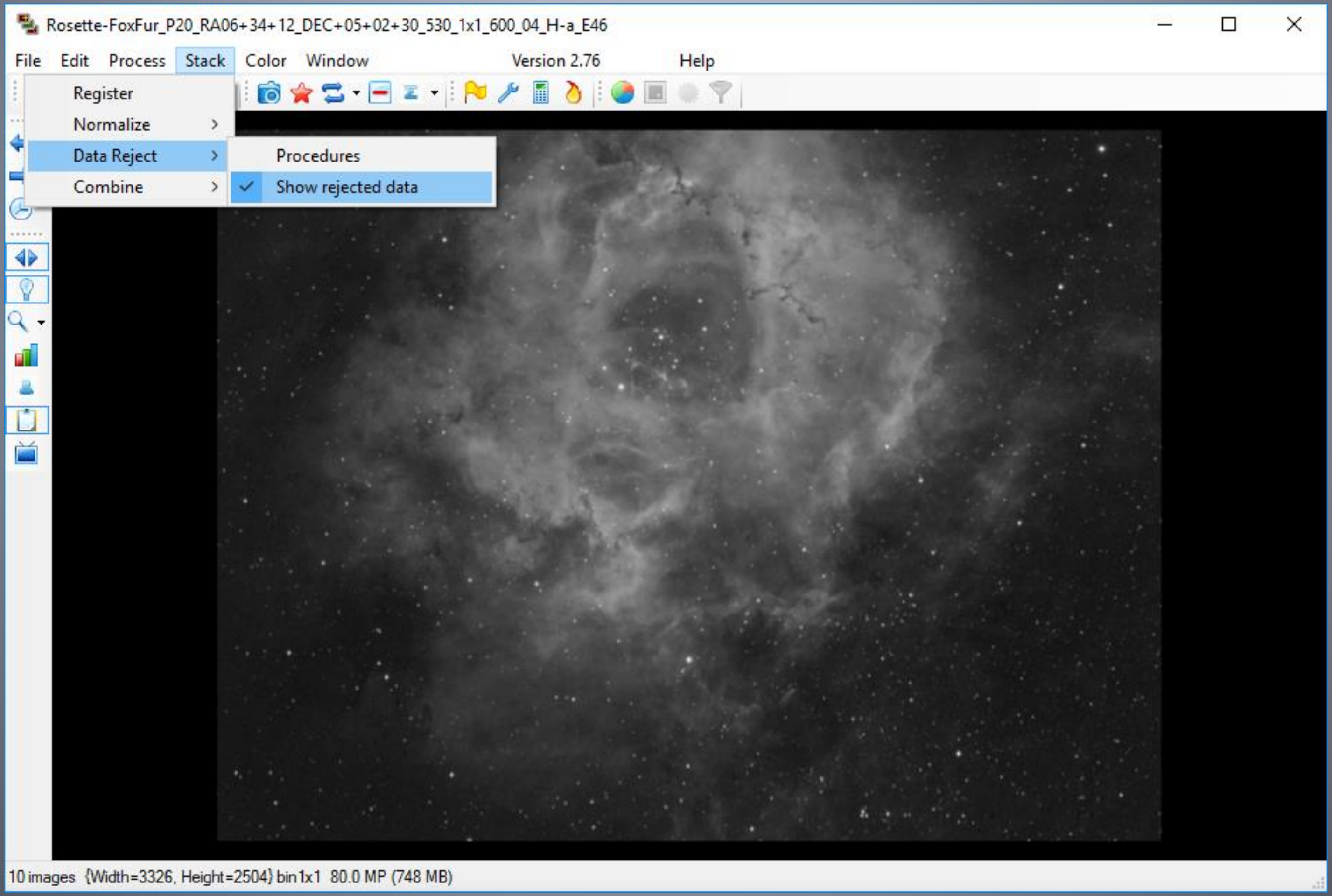
Set Include Status for All/Selected

Yes | No | Invert | Auto | Rename

Name	Include	DateTime	Exposur	Temp	Filter	FWH	Weight
Rosette-FoxFur_P20_RA06+34+12_DEC+05+02+30_530_1x1_600_04_H-a_E46	Y	2016-12-30	600	-30.1437	H-a	3.08	1
Rosette-FoxFur_P20_RA06+34+12_DEC+05+02+30_530_1x1_600_03_H-a_W21	Y	2016-12-29	600	-30.0651	H-a	3.22	0.77380
Rosette-FoxFur_P20_RA06+34+12_DEC+05+02+30_530_1x1_600_10_H-a_E44	Y	2017-01-04	600	-30.0840	H-a	3.24	0.64745
Rosette-FoxFur_P20_RA06+34+12_DEC+05+02+30_530_1x1_600_05_H-a_W44	Y	2016-12-30	600	-30.1186	H-a	3.3	0.96410
Rosette-FoxFur_P20_RA06+34+12_DEC+05+02+30_530_1x1_600_06_H-a_E26	Y	2016-12-31	600	-30.0777	H-a	3.72	0.95037
Rosette-FoxFur_P20_RA06+34+12_DEC+05+02+30_530_1x1_600_09_H-a_W26	Y	2017-01-03	600	-30.1029	H-a	3.72	0.87502
Rosette-FoxFur_P20_RA06+34+12_DEC+05+02+30_530_1x1_600_01_H-a_E46	Y	2016-12-28	600	-30.1532	H-a	3.78	1.00808
Rosette-FoxFur_P20_RA06+34+12_DEC+05+02+30_530_1x1_600_07_H-a_E48	Y	2017-01-01	600	-30.0243	H-a	4	1.04208
Rosette-FoxFur_P20_RA06+34+12_DEC+05+02+30_530_1x1_600_08_H-a_E48	Y	2017-01-01	600	-30.0746	H-a	4.38	1.21808
Rosette-FoxFur_P20_RA06+34+12_DEC+05+02+30_530_1x1_600_02_H-a_W37	Y	2016-12-28	600	-30.0966	H-a	4.42	1.00481

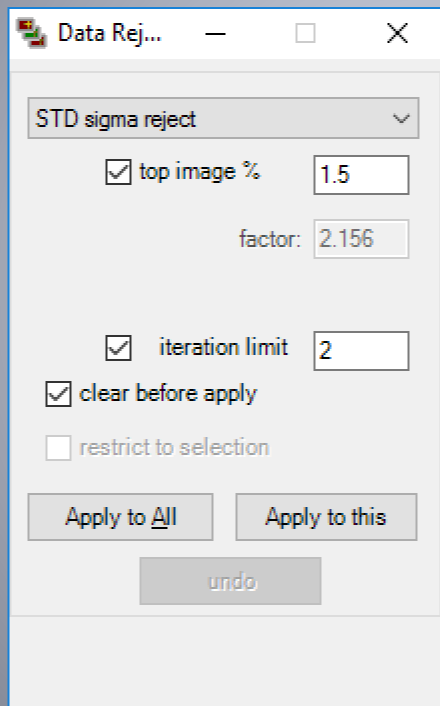
Creating wide-field mosaics
Data rejection and stacking

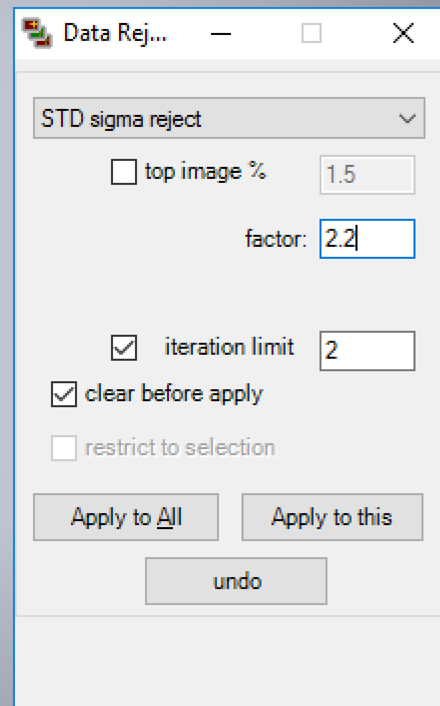
- Activate the option that shows the rejected data



Creating wide-field mosaics
Data rejection and stacking

- Click on the menu Stack->Data Reject->Procedures and select the "STD sigma reject" rejection algorithm

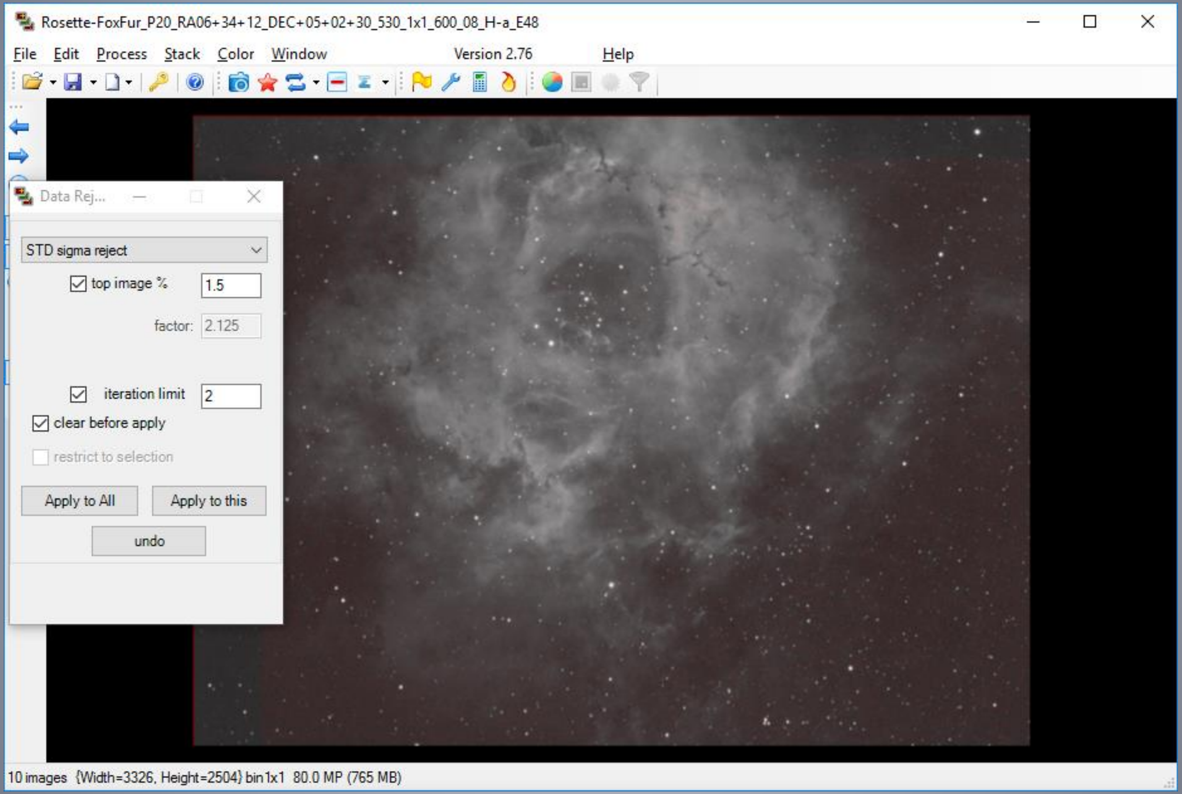




- You can either enter a value between 1% to 2% of the top image or directly enter a value in the factor

- Factor must be between 1.8 to 2.3 and the iteration limit must be set to 2 to reject at most two values. Press "Apply to All" button to process data rejection on each frames

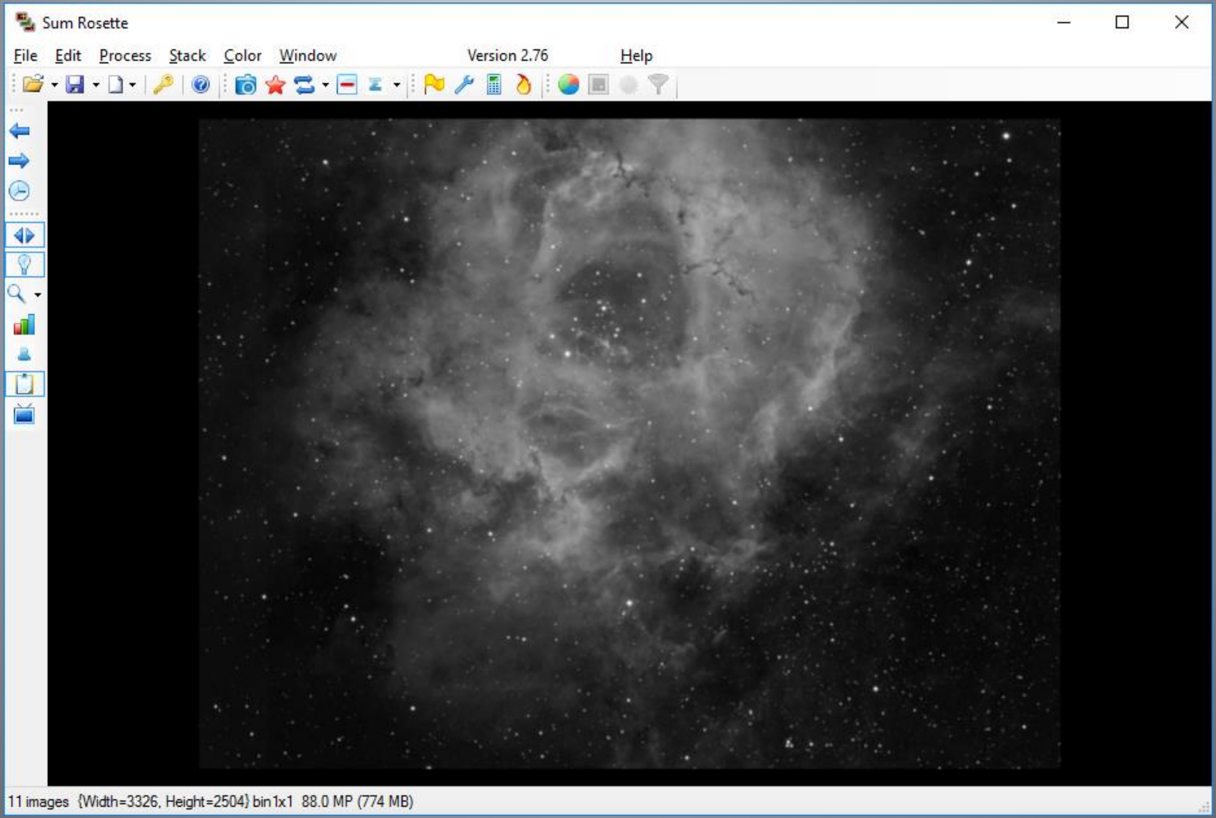
Creating wide-field mosaics
Data rejection and stacking



- The rejected pixels are highlighted in red on each frame
- Before stacking, each frame must be inspected to check if artifacts and imperfections have been correctly rejected
  - If not, the data rejection parameters must be adjusted and the rejection algorithm must be applied again

Creating wide-field mosaics
Data rejection and stacking

- Click on the menu
  - Use Stack->Combine->Sum to create a luminance master frame
  - Use Stack->Combine->Mean to create a monochromatic chrominance master frame



- Once generated, the master frame is added to the image manager

Creating wide-field mosaics
Data rejection and stacking

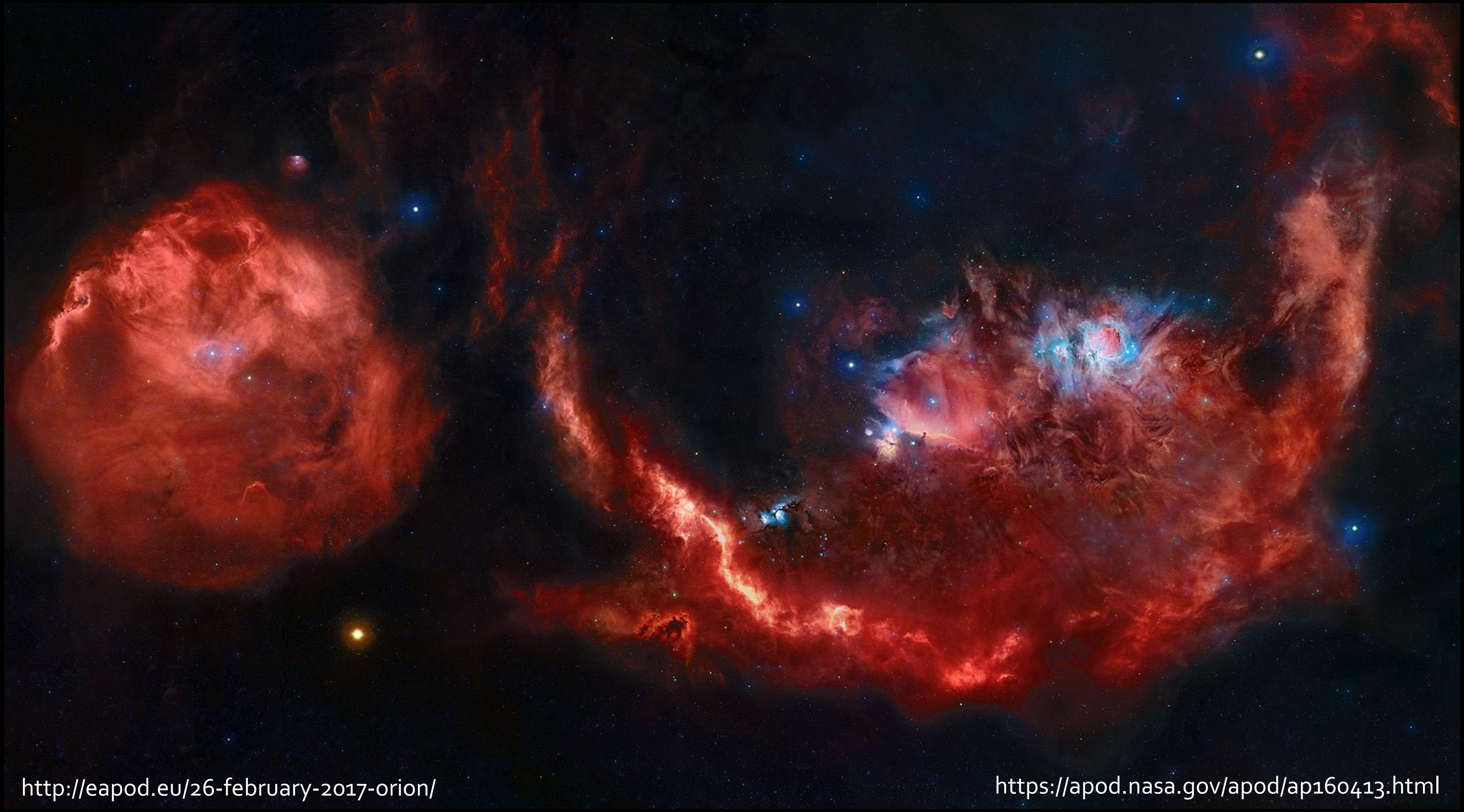
- Before saving the master frame, it must be carefully inspected to be sure that all imperfections and artifacts have been totally rejected
  - If not, the data rejection parameters must be adjusted, the rejection algorithm must be applied again and a new master frame must be generated

- Save the master frame
  - Usually, I create a subfolder called "stacked" in my project folder
  - I use this subfolder to store all master frames that will be used to create mosaic master frame by stitching all individual tile master frame

- To give a useful filename to the master frame, I follow this naming convention:

Sum_Rosette-FoxFur_P20_RA06+34+12_DEC+05+02+30_530_1x1_6000_10_H-a.fit

- Sum: Stacking operation
- Rosette-FoxFur: Mosaic project name
- P20: Tile number
- RA06+34+12: Right ascension coordinate of the center
- DEC+05+02+30: Declination coordinate of the center
- 530: Focal length in millimeters
- 1x1: Binning
- 6000: Total exposure time in seconds
- 10: Subframe number
- H-a: Filter name



Orion (180 panels mosaic)

Chapter 8: Mosaic stitching

Creating wide-field mosaics
Mosaic stitching

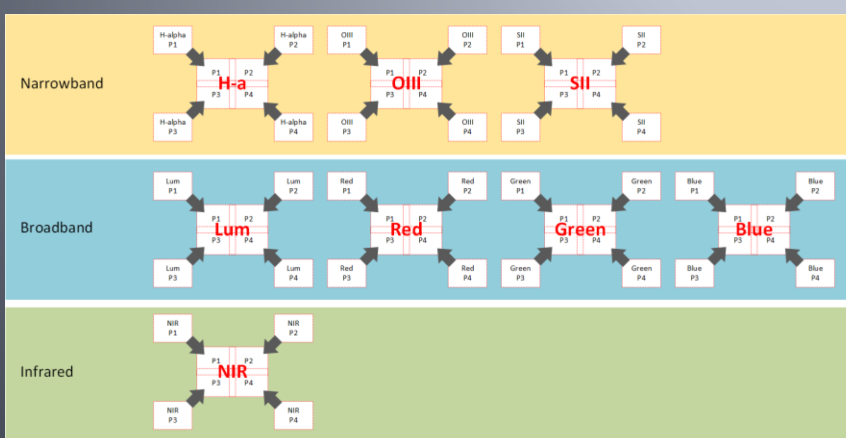
- This is the second most challenging phases in the mosaic project life cycle

- To accomplish that we must be patient and resilient, indeed there is two major cliffs that must be overcome:
  - The first one is to register each tile master frames together to build a unique mosaic master frame
  - The second one is to merge all registered tile master frames into a unique seamless* image

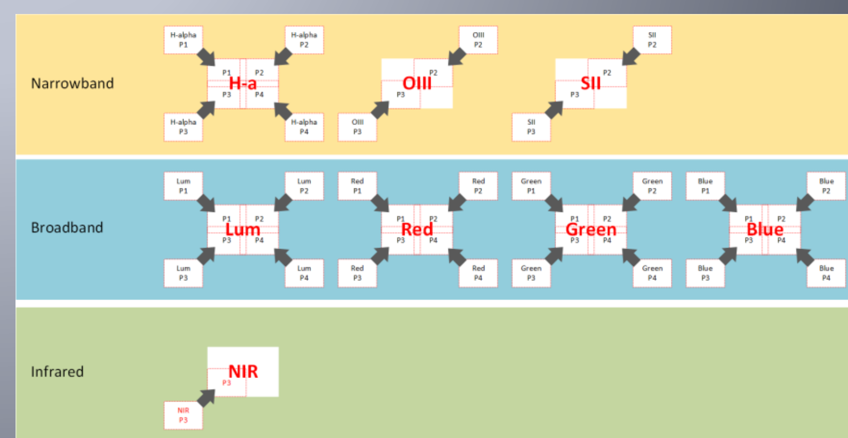
    **seamless means that the overlap between tiles must not be visible on the final image*

- Several workflows exist to stitch a mosaic. Mainly, I use a workflow that merge all monochromatic master tile frames captured with the same filter into a unique monochromatic mosaic master frame

- All mosaic master frames can be symmetric (merged with the same number of tiles and covering the same field) or asymmetric (merged with various numbers of tiles and not covering the same field)



Symmetric stitching workflow



Asymmetric stitching workflow

Creating wide-field mosaics
Mosaic stitching

- This workflow is the most demanding in term of registration but in the other hand it provides the greatest control at processing

- The time we will spend for stitching is directly proportional to the number of tiles that the project contains:
  - The more is the number of tiles, the more the risk of mismatches increase
  - The more is the mismatches, the more the time needed to solve them is long

- To make an example, I spent 120 hours to complete the asymmetric stitching workflow that allowed to merge more than 180 monochromatic frames of the following mosaic

- For this mosaic, the workflow is asymmetric because the mosaic field is covered at 100% by H-alpha, Red, Green, and Blue data and partially covered by OIII, SII, NIR and Luminance data

Creating wide-field mosaics

Mosaic stitching

- To register and to merge master tile frame, I usually work with two different software: RegiStar and PixInsight

- Registar is software that is only specialized in automatic image registration for astrophotography

- Auriga Imaging describes RegiStar as following:

RegiStar is a one-of-a-kind program that fully automates the task of aligning digital astronomical images. RegiStar shifts, rotates, flips, and deforms as needed to precisely align images, even if they are at different scales or orientations or have been produced with different optical systems

- PixInsight is an image processing platform specialized in astrophotography offering a wide variety of tools and processing algorithms

- Pleiades Astrophoto describes PixInsight as following:

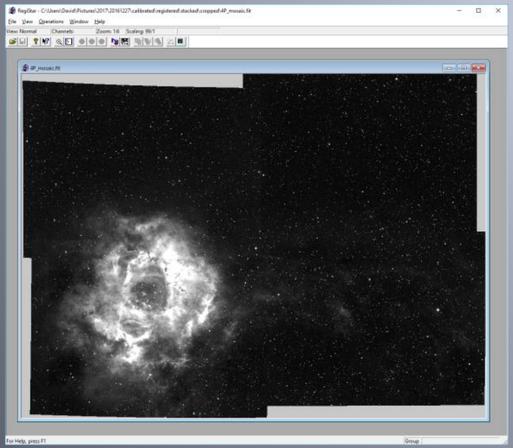
PixInsight is our main development project. It is an image processing platform specialized in astrophotography, available natively for FreeBSD, Linux, Mac OS X and Windows operating systems. PixInsight is both an image processing environment and a development framework. It is the result of a dynamic collaboration between like-minded astrophotographers and software developers, who are constantly pushing the boundaries of astronomical image processing with the most powerful toolset available

Creating wide-field mosaics
Mosaic stitching

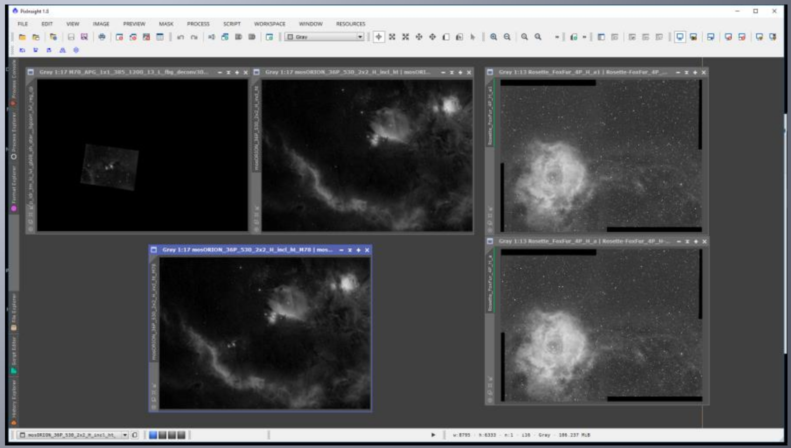
- In my experience, I found that PixInsight is more efficient for merging frames and RegiStar is more efficient for registering frames particularly if they have different scales or orientations or have been captured with different optical systems

- But both are able to stitch a mosaic from A to Z

- Depending on the issues encountered while stitching, I use only RegiStar, only PixInsight or both together



Registar

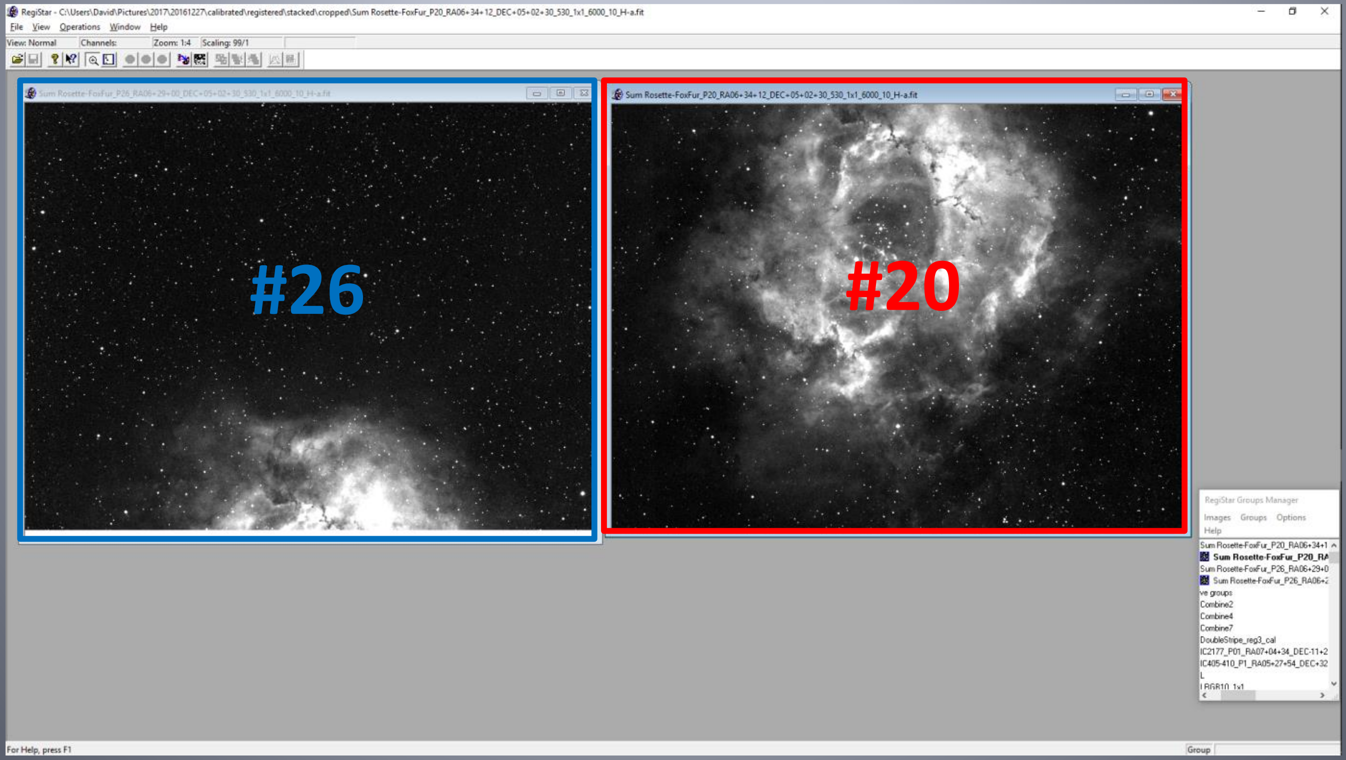


PixInsight

Creating wide-field mosaics
Mosaic stitching

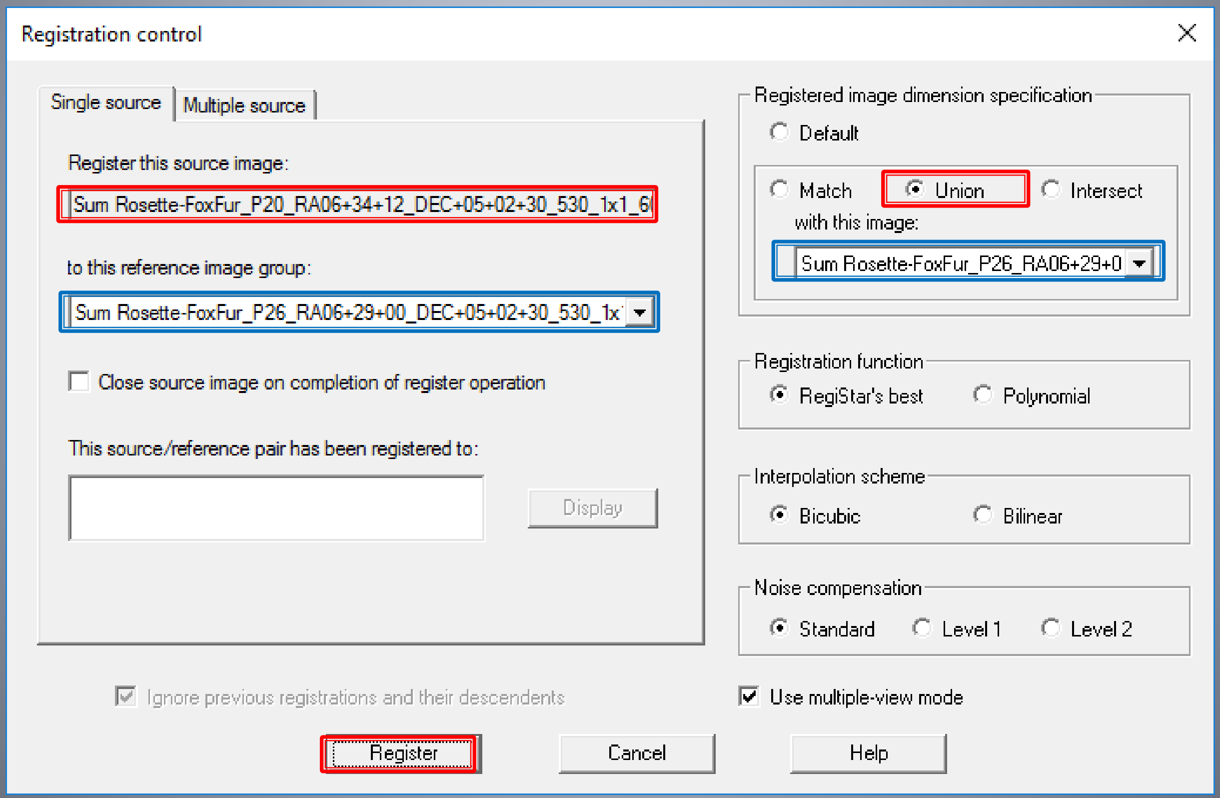
- With RegiStar, I use the following workflow:

- Open RegiStar
- Load two tiles that overlaps each other's



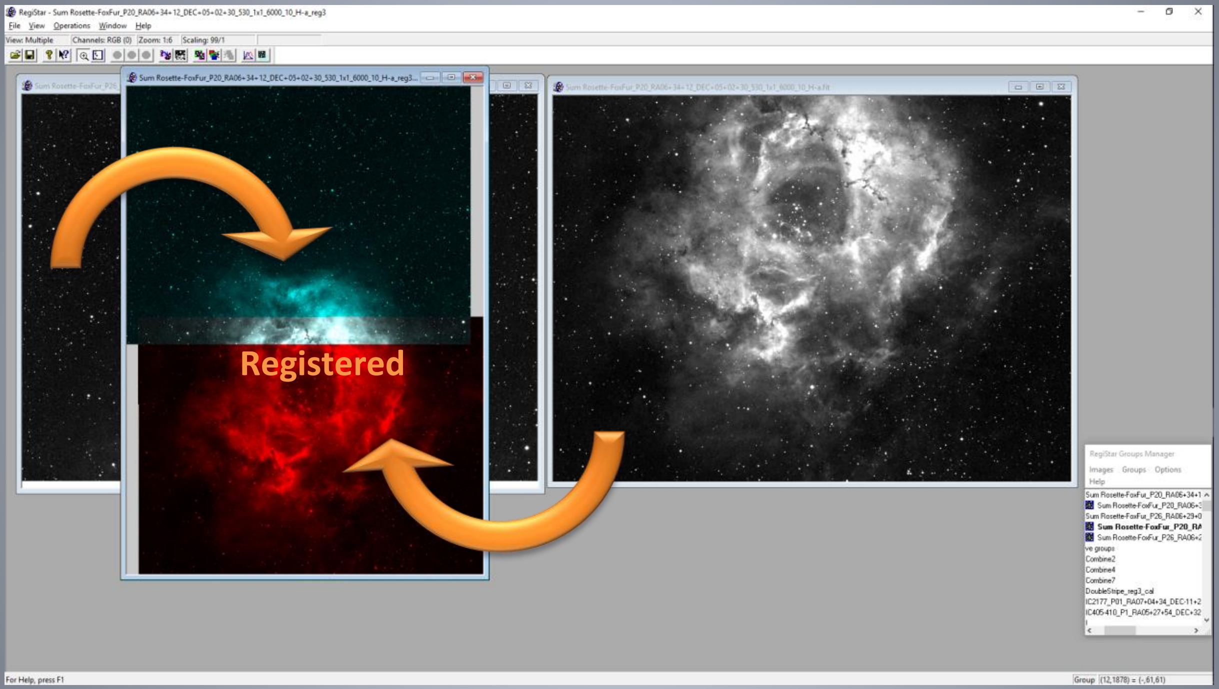
Creating wide-field mosaics
Mosaic stitching

- Click on menu Operations->Register (or press F2)



- Choose Union and click on “Register” button

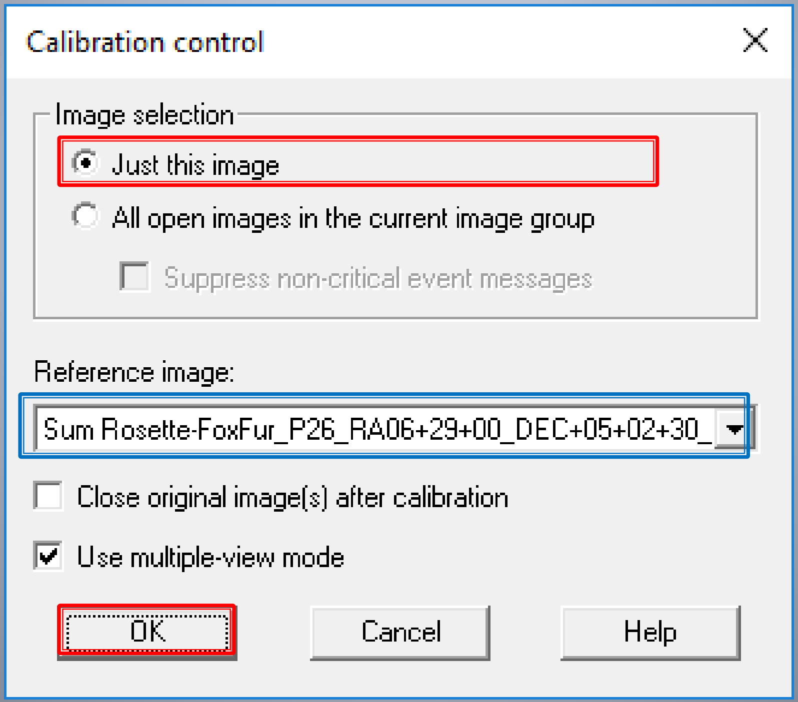
Creating wide-field mosaics
Mosaic stitching



- The tile in red #20 is automatically registered with the tile in blue #26
- Before merging the tiles together, they must be calibrated first
- Calibration means equalization of their signal level. To be correctly calibrated both tiles must share at least 1000 pixels

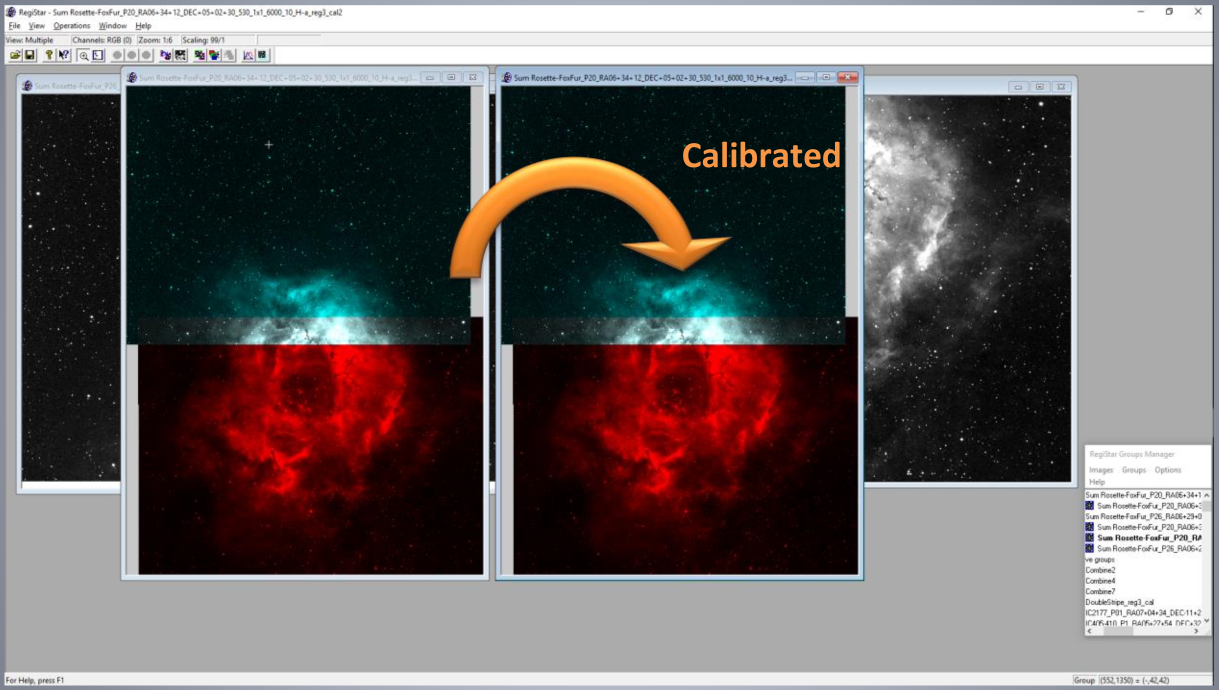
Creating wide-field mosaics
Mosaic stitching

- To calibrate the red tile #20 against the blue tile #26, click the menu Operations->Calibrate (or press F7)



- Select "Just this image" and the image #26 as reference and click the "OK" button

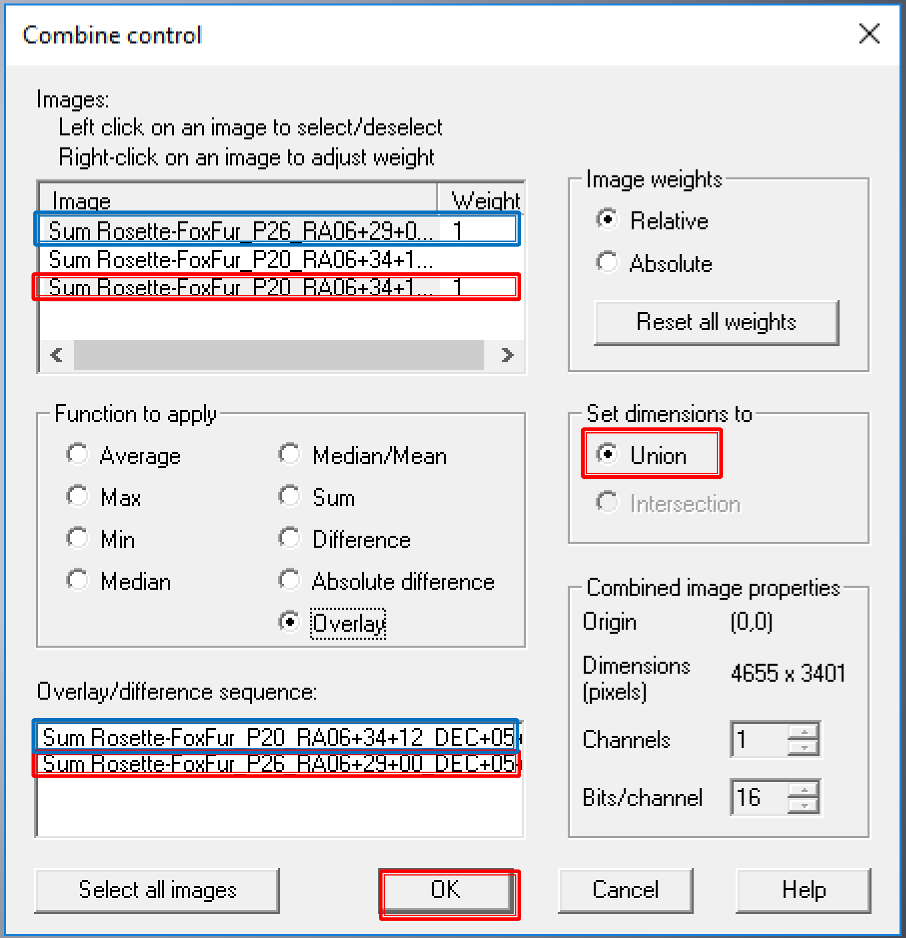
Creating wide-field mosaics
Mosaic stitching



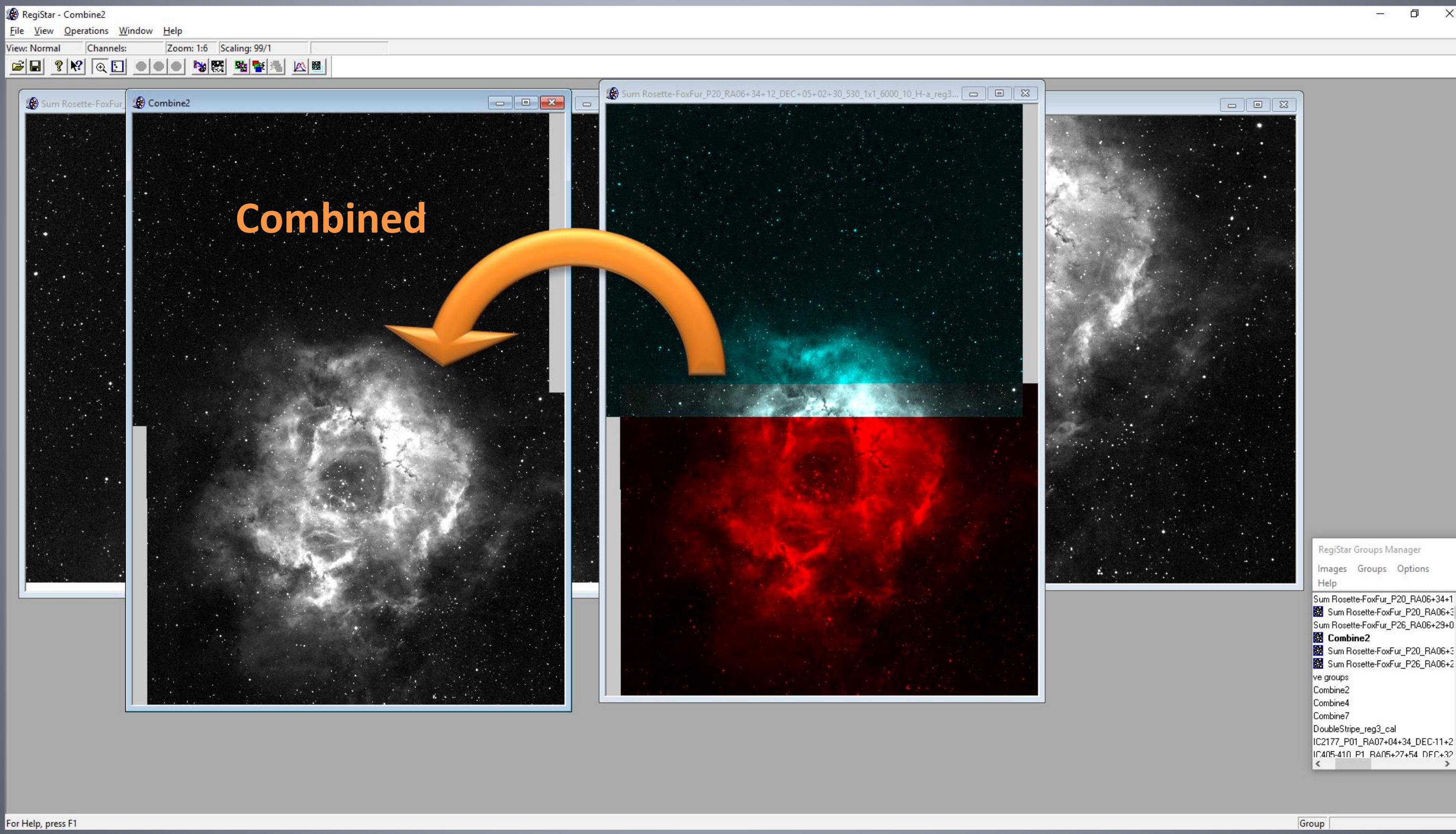
- After calibration, the result is displayed in a new window
- Now, the calibrated tiles can be combined together to generate a single frame

Creating wide-field mosaics
Mosaic stitching

- To combine the red tile #20 with the blue tile #26, click the menu Operations->Combine (or press F4)
- There are several functions that can be used to combine, I usually use Overlay because it generally gives the best result
- Overlay specifies that images are superimposed in a specified order, with each image replacing those below it (blue #26 replace red #20)
- Press "OK" to combine



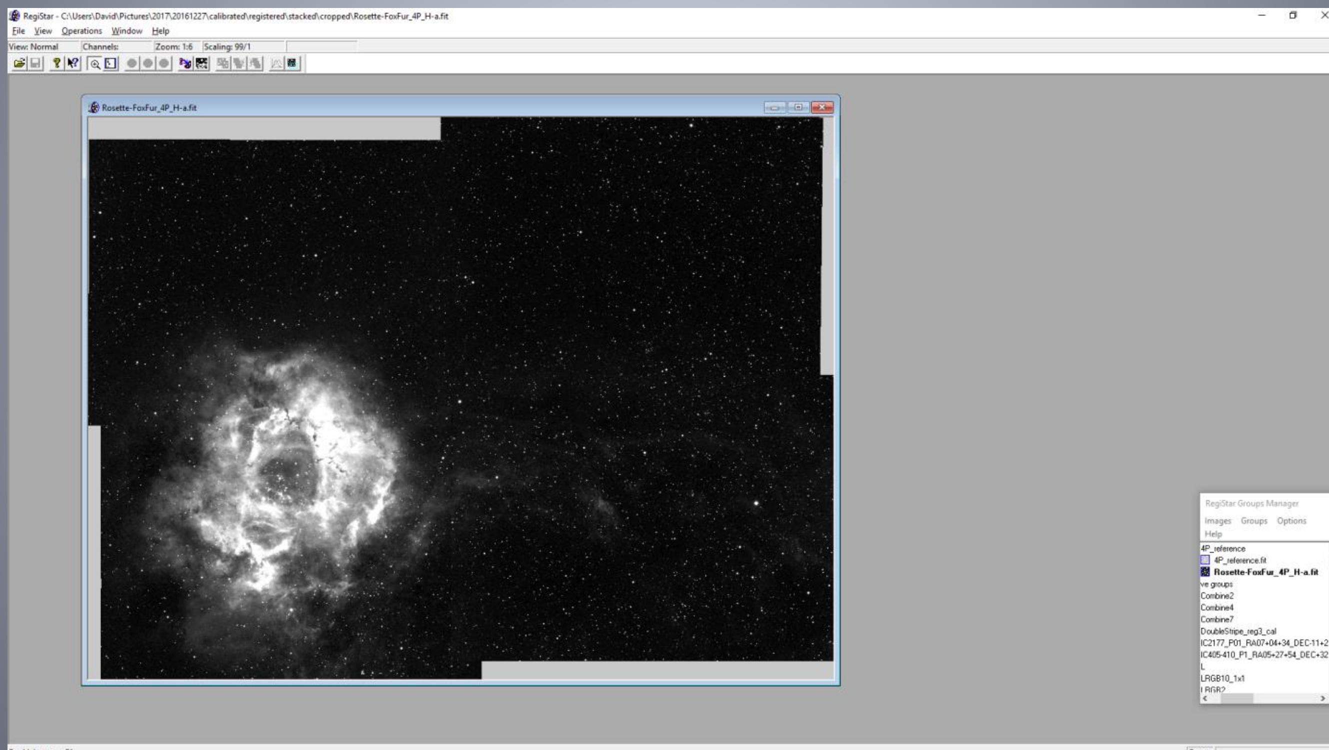
Creating wide-field mosaics
Mosaic stitching



- After combine, the result is displayed in a new window

Creating wide-field mosaics
Mosaic stitching

- Continue with the same workflow until all tiles get assembled

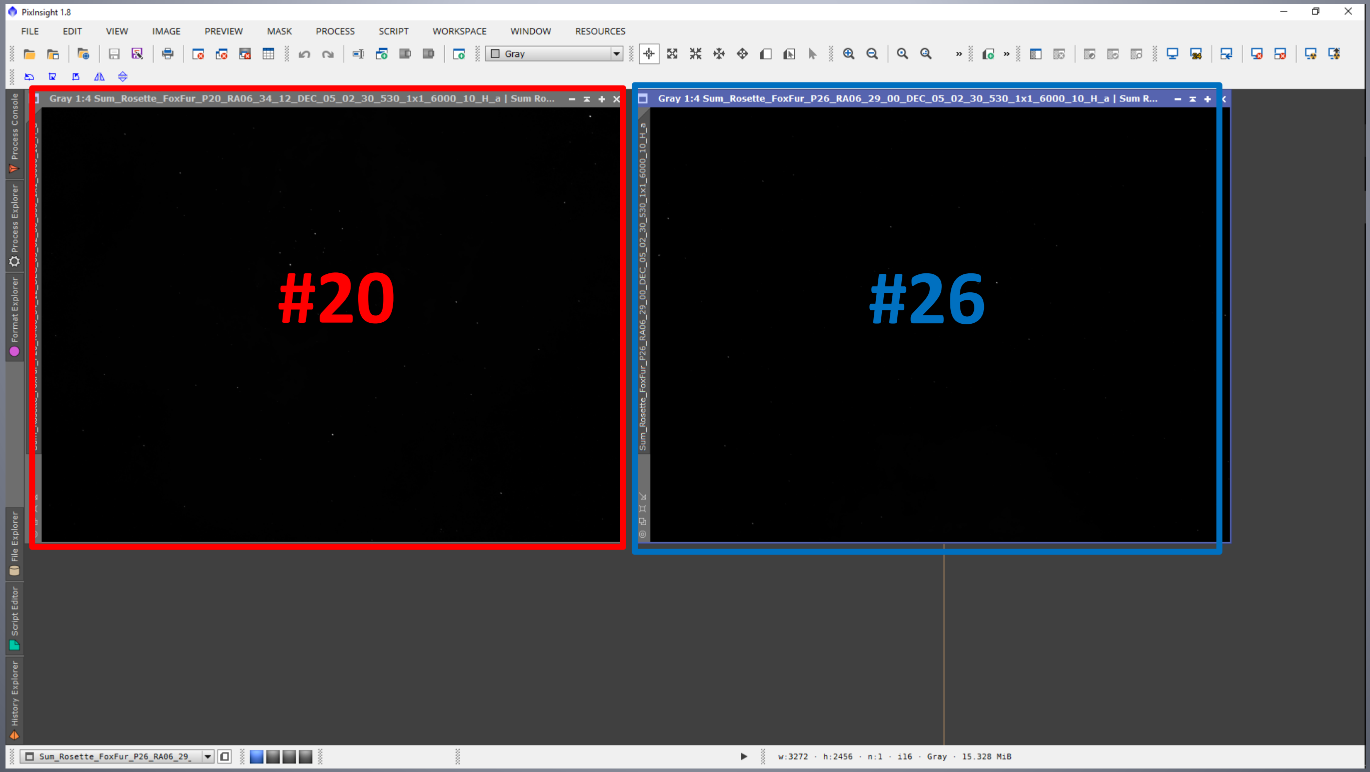


- Save the monochromatic mosaic master frame on the project folder

Creating wide-field mosaics
Mosaic stitching

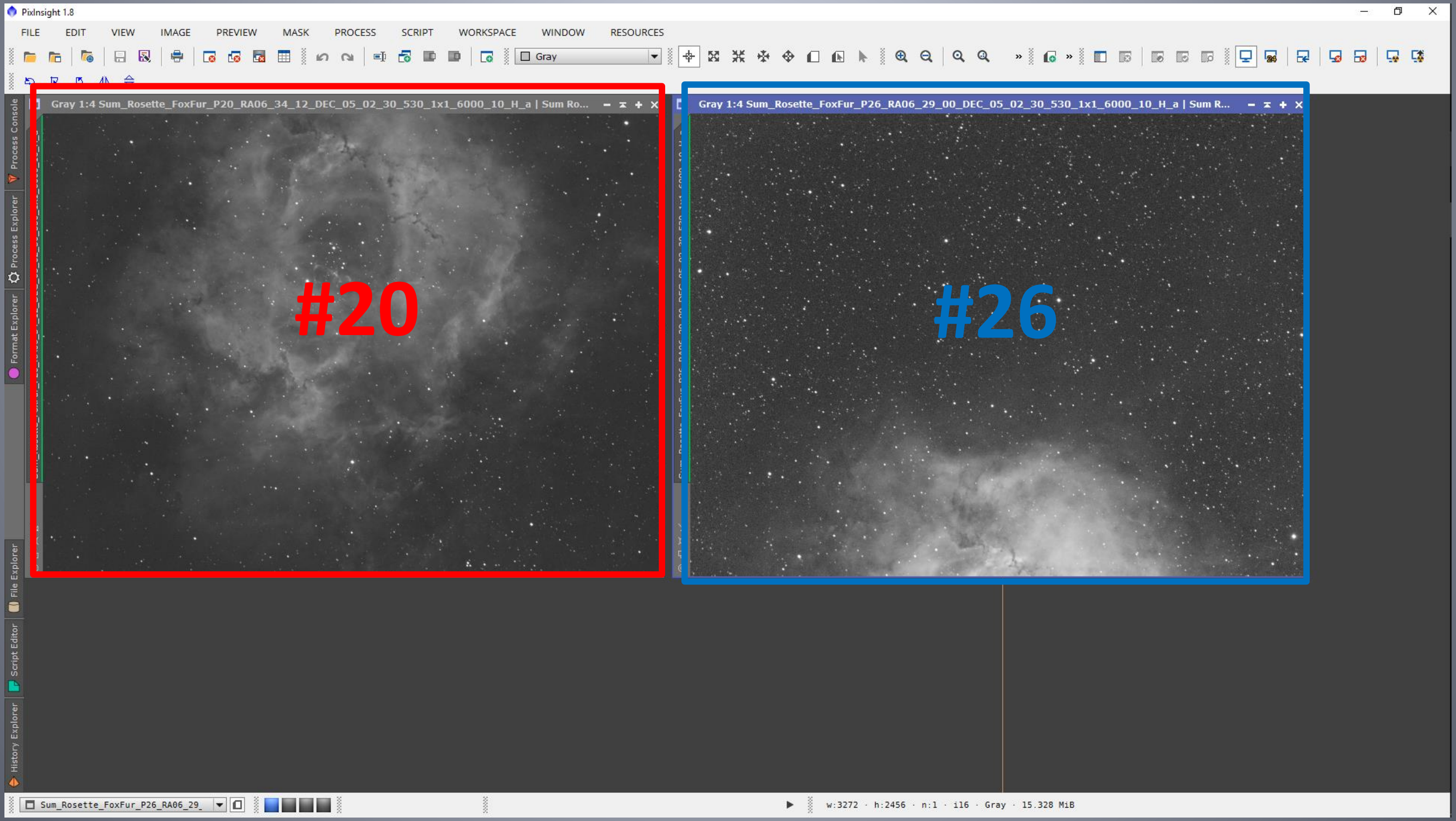
- With PixInsight, I use the following workflow

- Open PixInsight
- Load two tiles that overlaps each other's



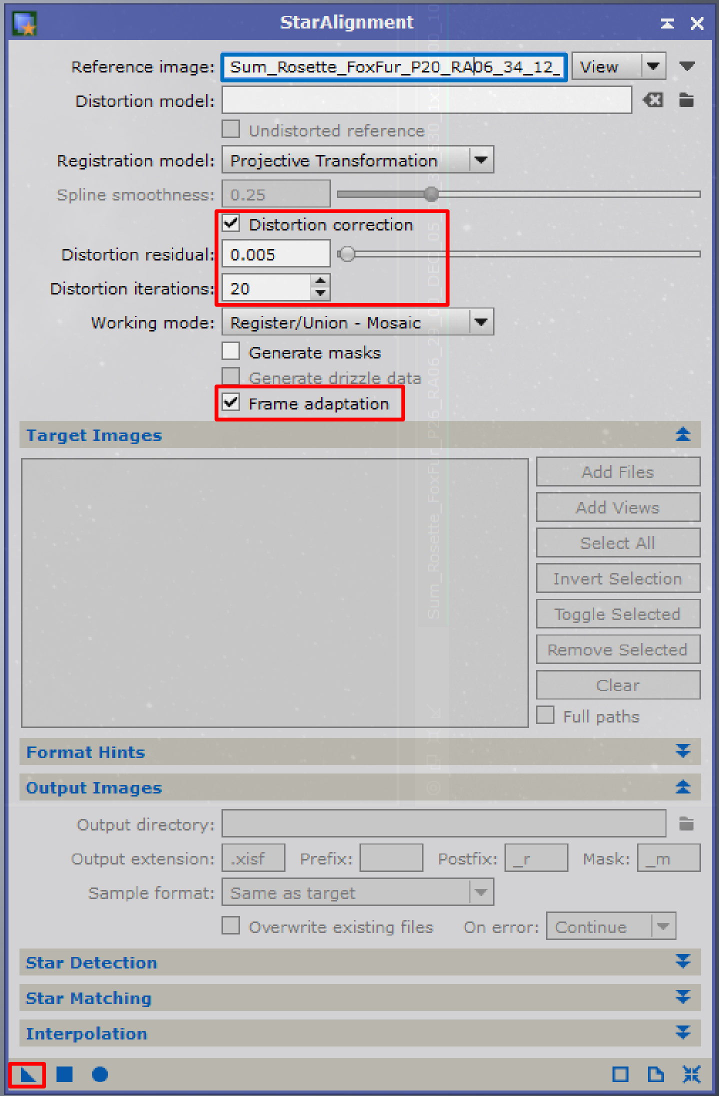
Creating wide-field mosaics
Mosaic stitching

- Press CTRL + A on both to apply screen transfer function to see the images details



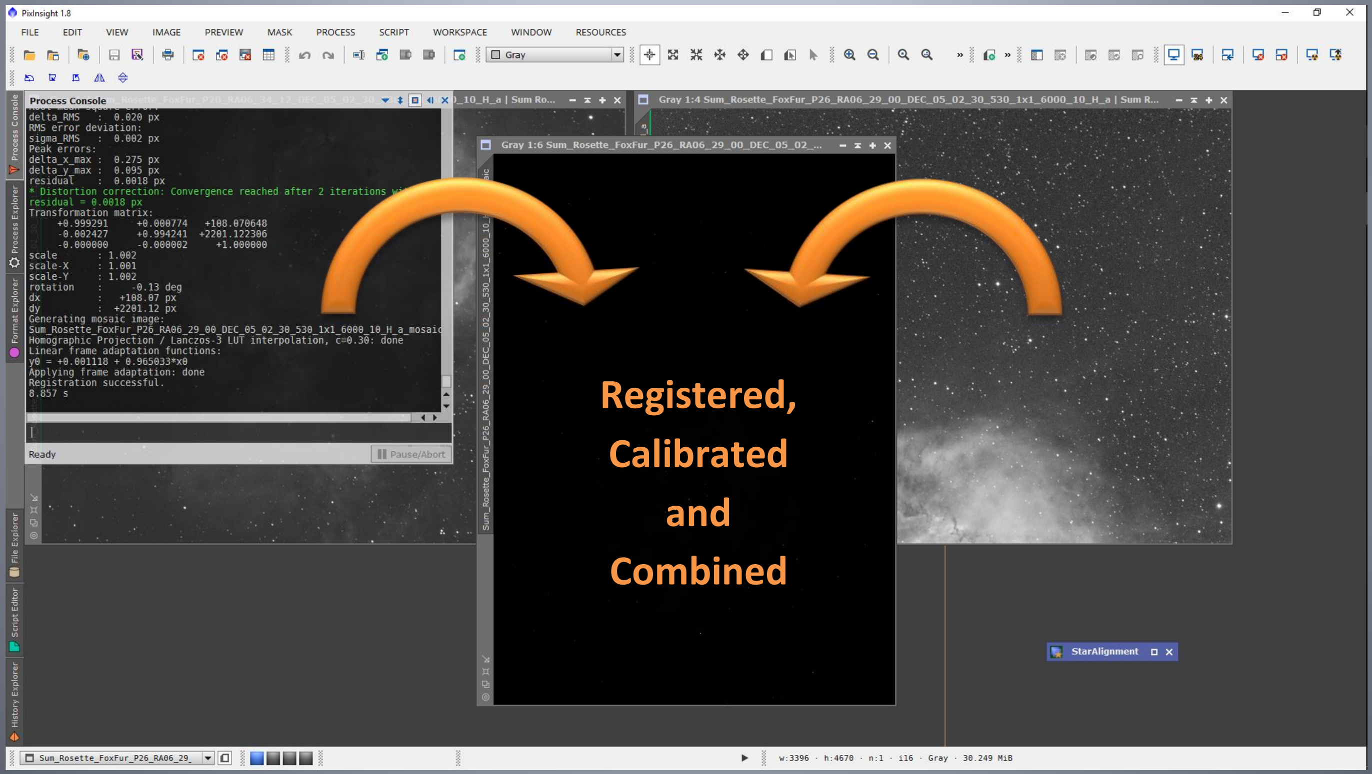
Creating wide-field mosaics
Mosaic stitching

- From Process Explorer, select the StarAlignment process
- Select the tile #20 as a reference image, activate the distortion correction and adjust the number of iterations and residual parameters if needed
  - Try first with default value and adjust them later if the distortion can't be corrected with default settings.
- Check frame adaptation to equalize the signal level of the tile #26 against the tile #20
- Drag & Drop the triangle located at bottom left on the tile #26 to start the registration and combine process

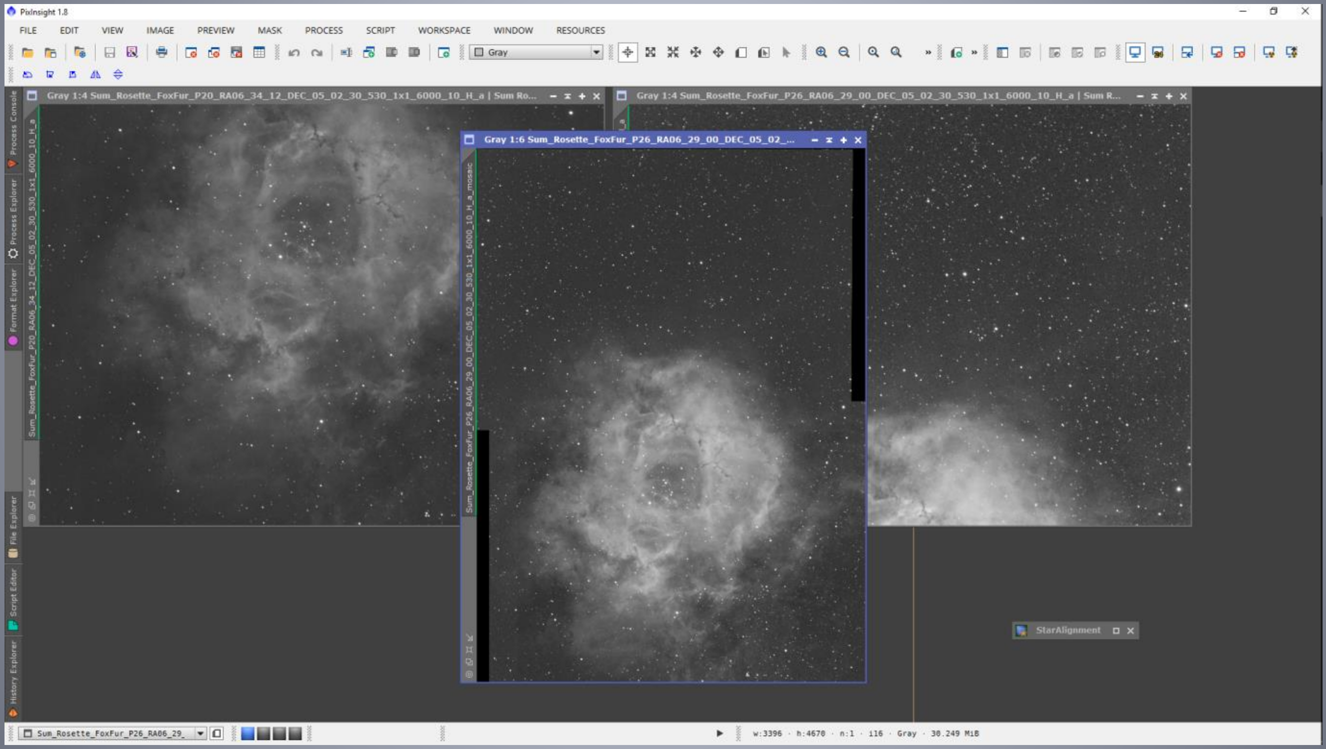


Creating wide-field mosaics
Mosaic stitching

- At the end of the process, a new frame is displayed to display the new image details press CTRL+A

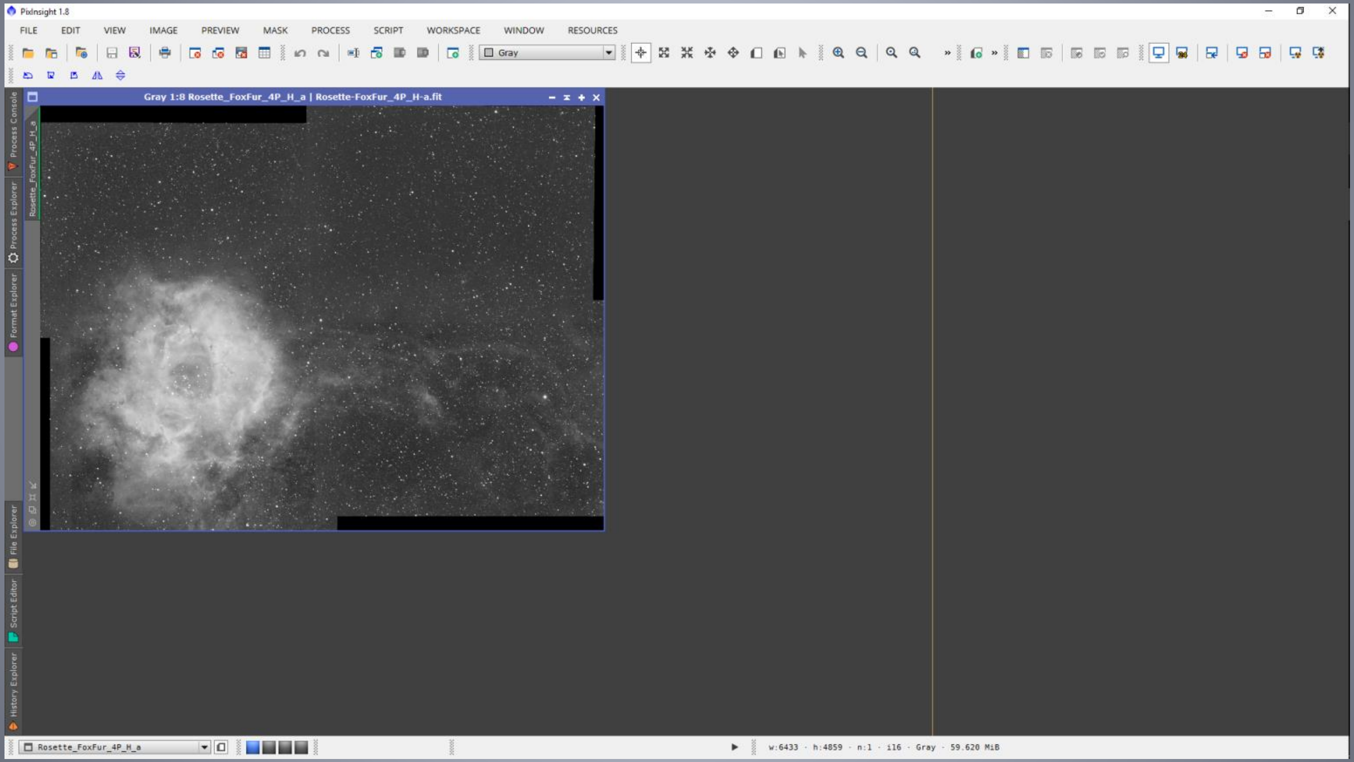


Creating wide-field mosaics
Mosaic stitching



- Continue with the same workflow until all tiles get assembled

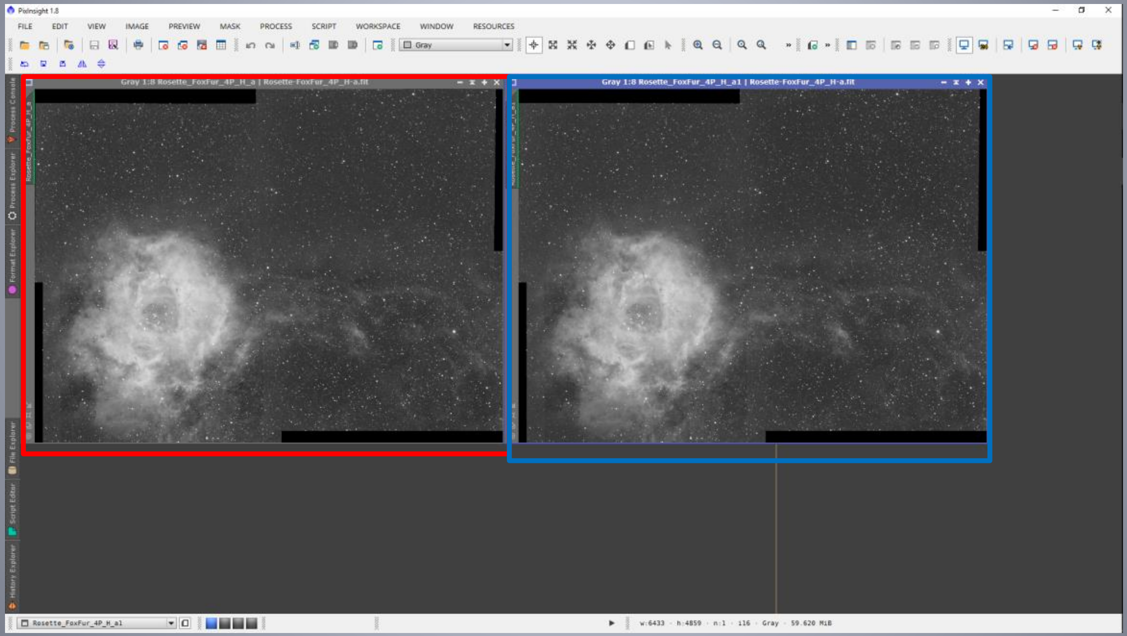
Creating wide-field mosaics
Mosaic stitching



- Save the monochromatic mosaic master frame in the project folder
  - Usually, I create a subfolder called "stitched" in my project folder

Creating wide-field mosaics
Mosaic stitching

- If we compare the results made with the two workflows: in red the mosaic frame built with PixInsight and in blue with Registar



- In that example, the results look exactly the same; there are no apparent differences and the result looks almost seamless. The adjustments that are required to get a perfect result only require little adjustments that can be done later with proper mask and curve tools in PhotoShop

Creating wide-field mosaics
Mosaic stitching

- The raw data used to build the example are very homogeneous; the 4 frames share the same scale (dimensions and pixel FOV) and almost the same quality
  - almost the same SNR and few distortions

- The use of homogeneous data does not allow figuring out any differences between the two workflows

- But in case of use of heterogeneous data (various dimensions, pixel FOV, quality and SNR), I found that Registar is the best tool to achieve an accurate registration of every frames

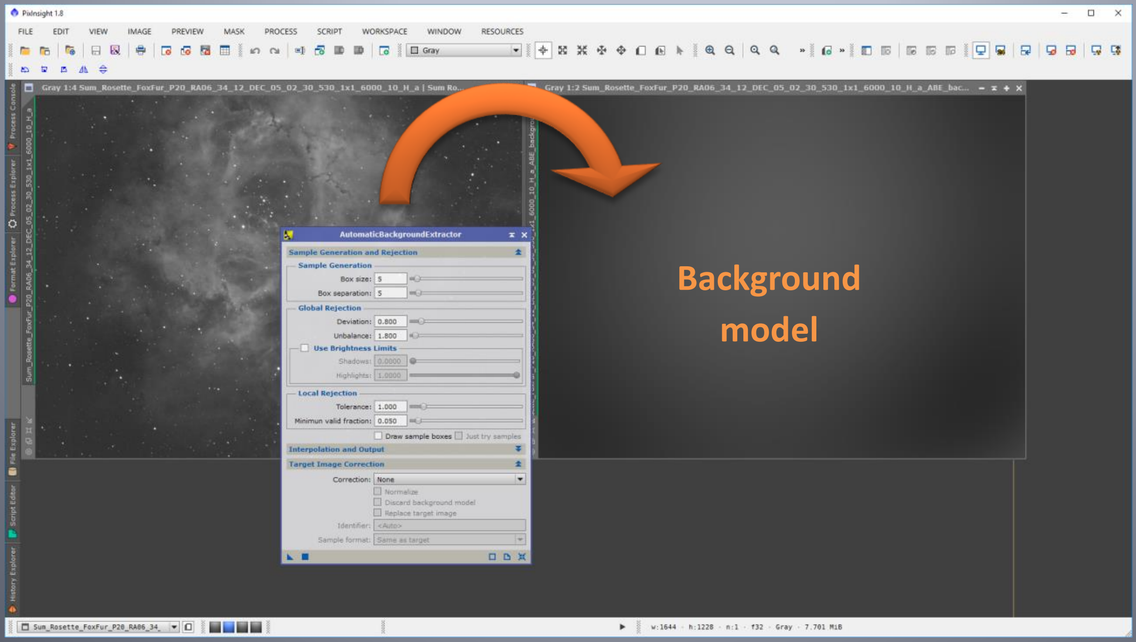
Creating wide-field mosaics

Mosaic stitching

- In the case that the mosaic master frame built by using the standard stitching workflows does not give a seamless result. PixInsight is able to create smooth transition between tiles with two processes BackgroundExtraction (ABE and DBE) and GradientMergeMosaic (GMM)
- Very often the seams appears between tiles because of a light pollution gradient
- So before using GMM process try to remove the light pollution gradient on each contaminated frame
- Once the gradient is removed, the tiles must be registered against the previously generated mosaic master frame
- Once they are registered, they can be merged by using the GMM process

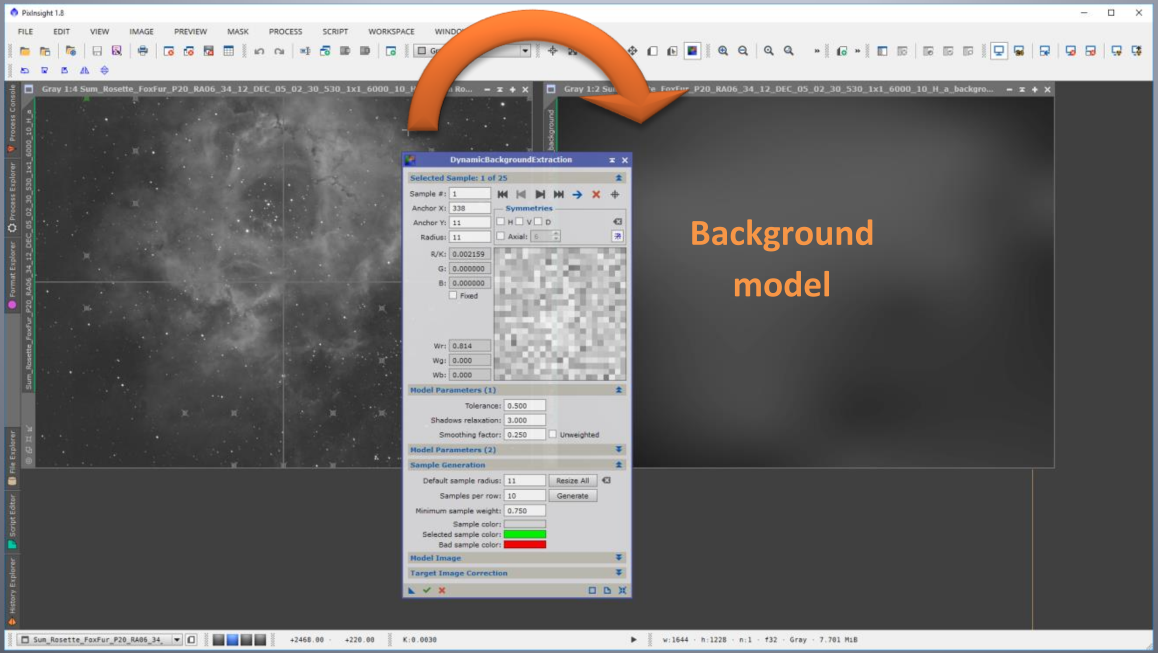
Creating wide-field mosaics
Mosaic stitching

- Usually, I start with AutomaticBackgroundExtraction (ABE) because it performs a linear least square fit and attempts to remove gradients automatically without user interactions
- As first step, I apply ABE on a light polluted frame without correction
- I carefully inspect the generated background model and if it looks good, I subtract it from the light polluted frame



Creating wide-field mosaics
Mosaic stitching

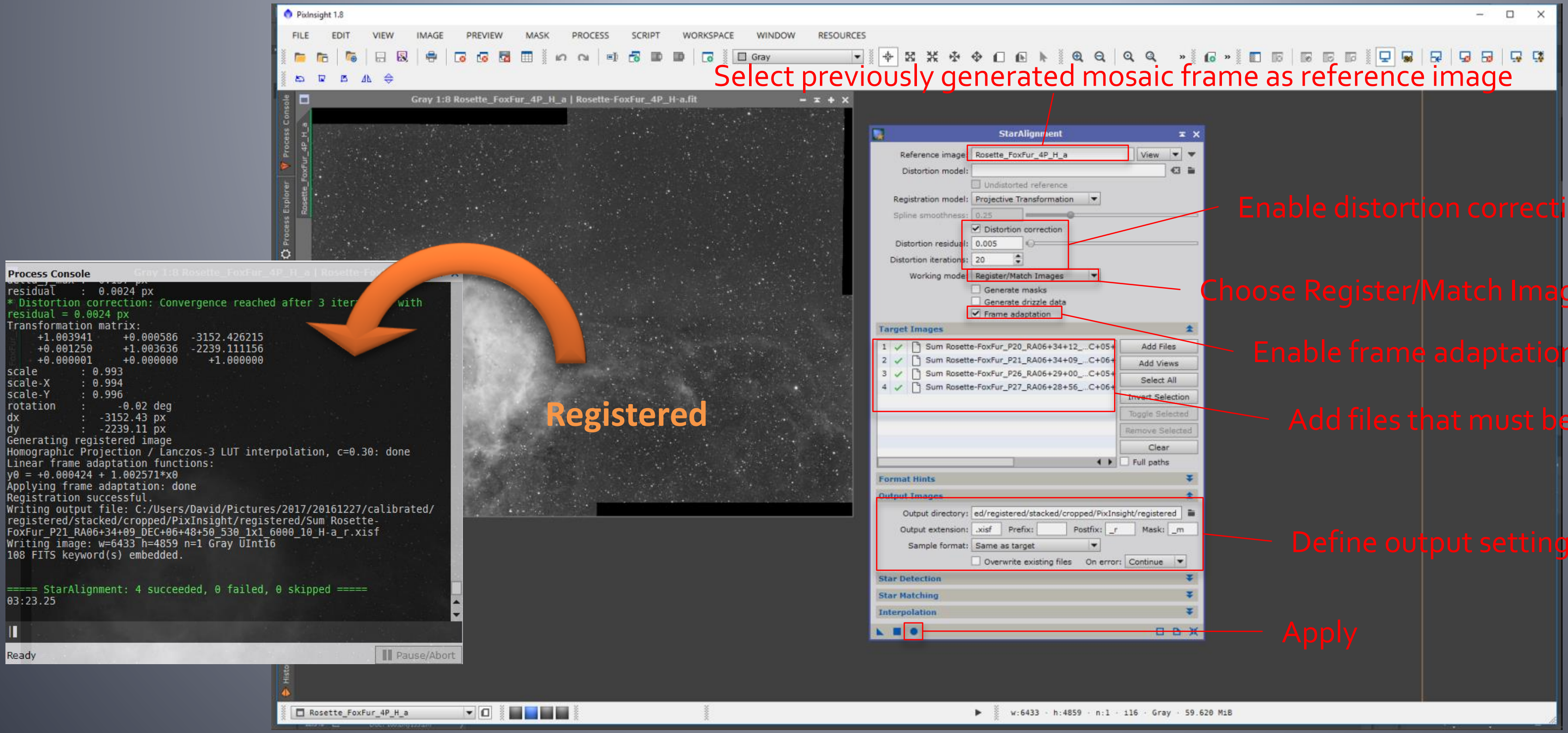
- If light pollution gradient are difficult to eliminate, I use DynamicBackgroundExtraction (DBE) to manually build a custom background model
- As first step, I generate samples and I apply DBE without correction
- I carefully inspect the generated background model and if it looks good, I subtract it from the light polluted frame



Creating wide-field mosaics
Mosaic stitching

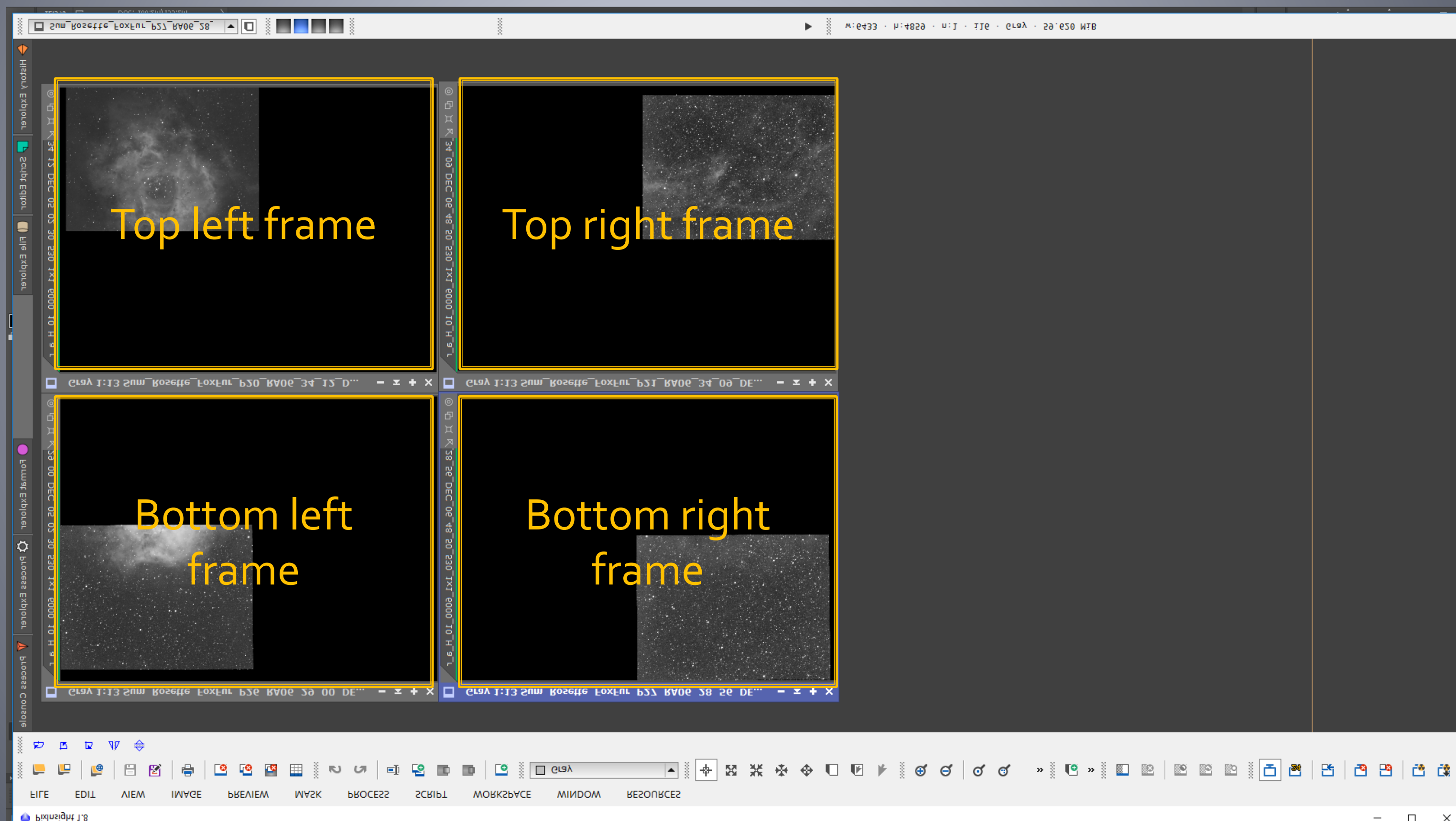
- Once the gradient has been properly removed, the gradient mosaic merge GMM can be applied according the following workflow:

- Open PixInsight
- Load the previously generated mosaic frame
- Open the StarAlignment process



Creating wide-field mosaics
Mosaic stitching

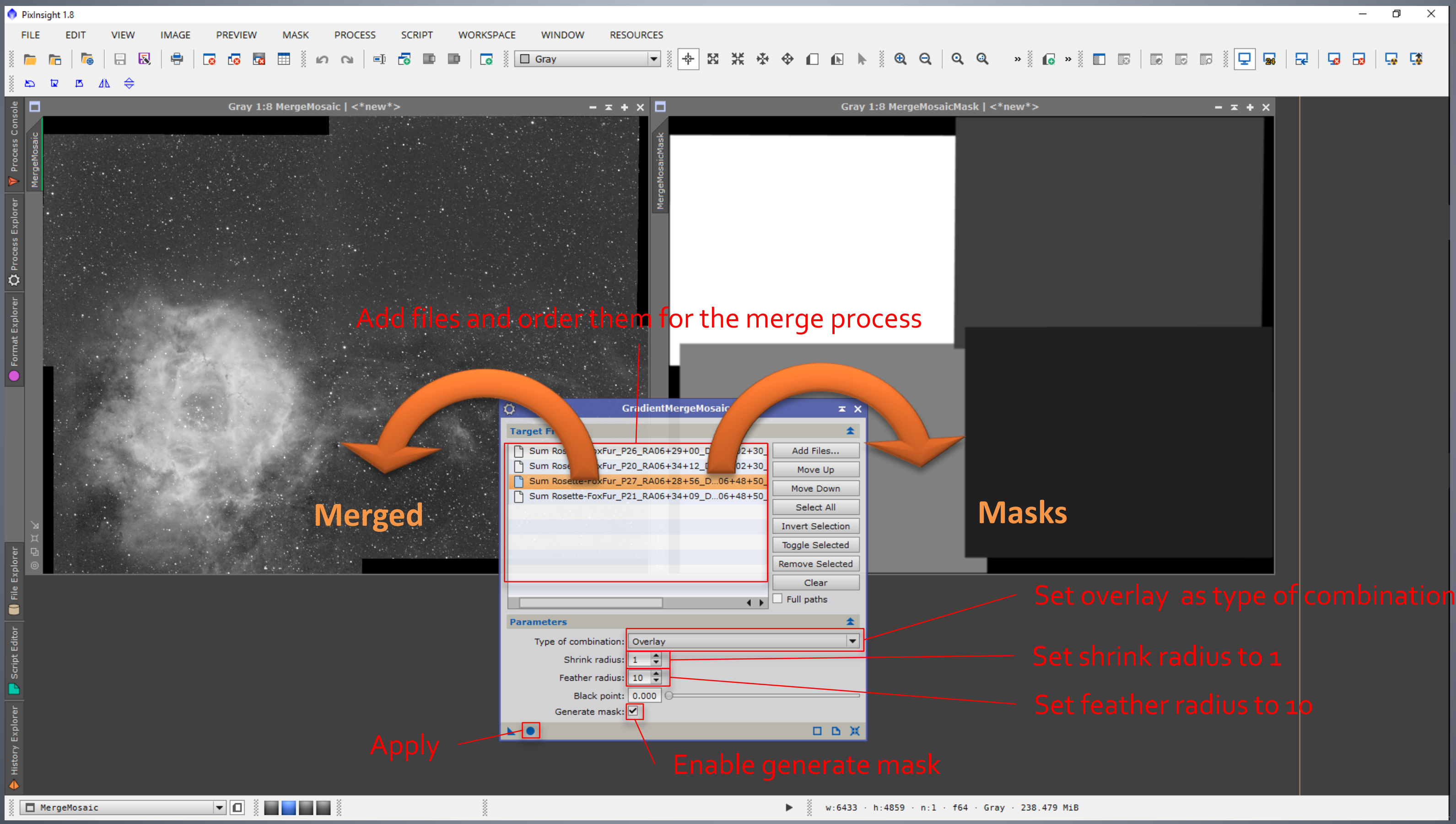
- Load the registered frame and press CTRL+A to see the details



- Inspect each frame and check if they are correctly registered

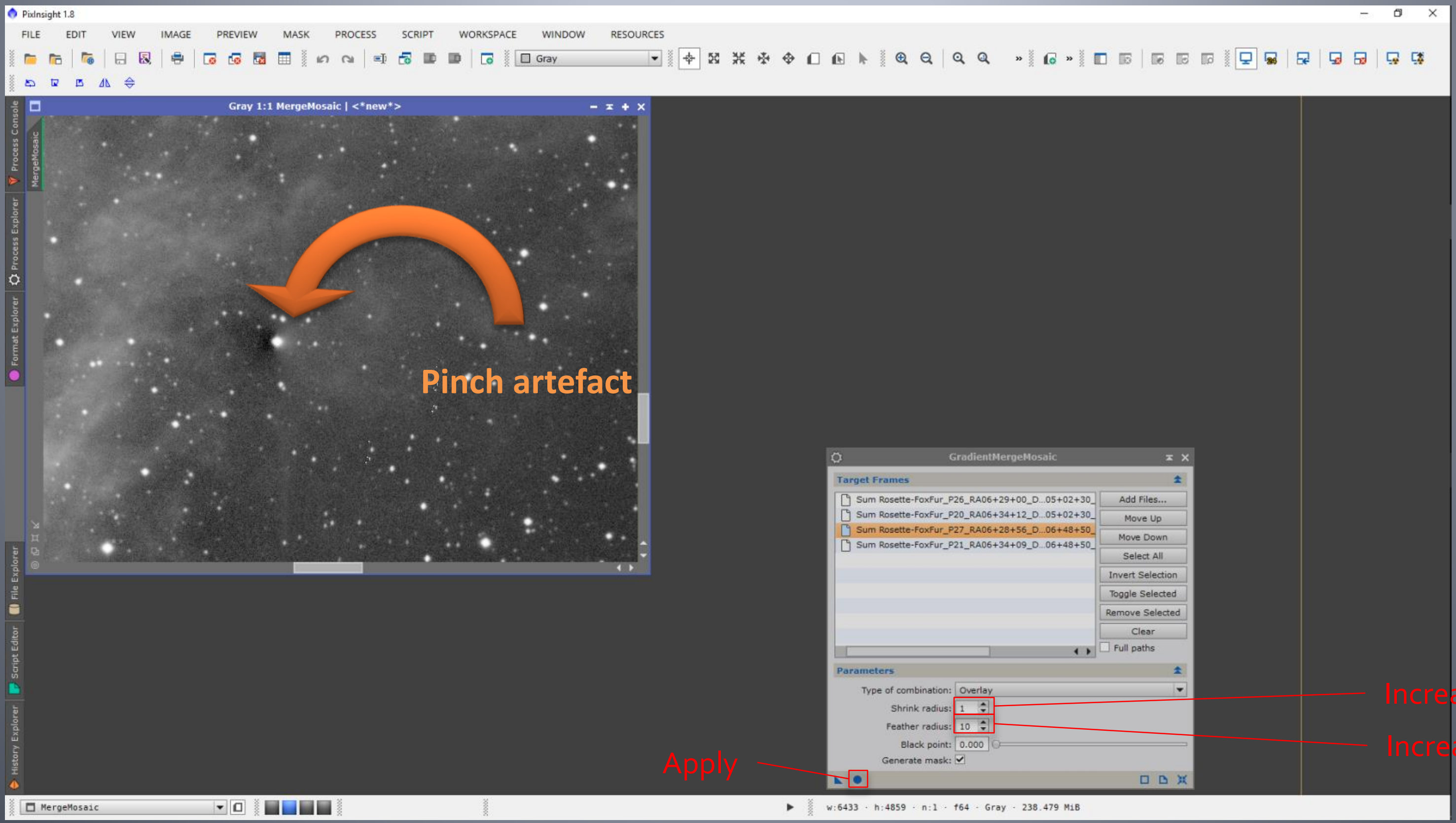
Creating wide-field mosaics
Mosaic stitching

- Open the GradientMergeMosaic process



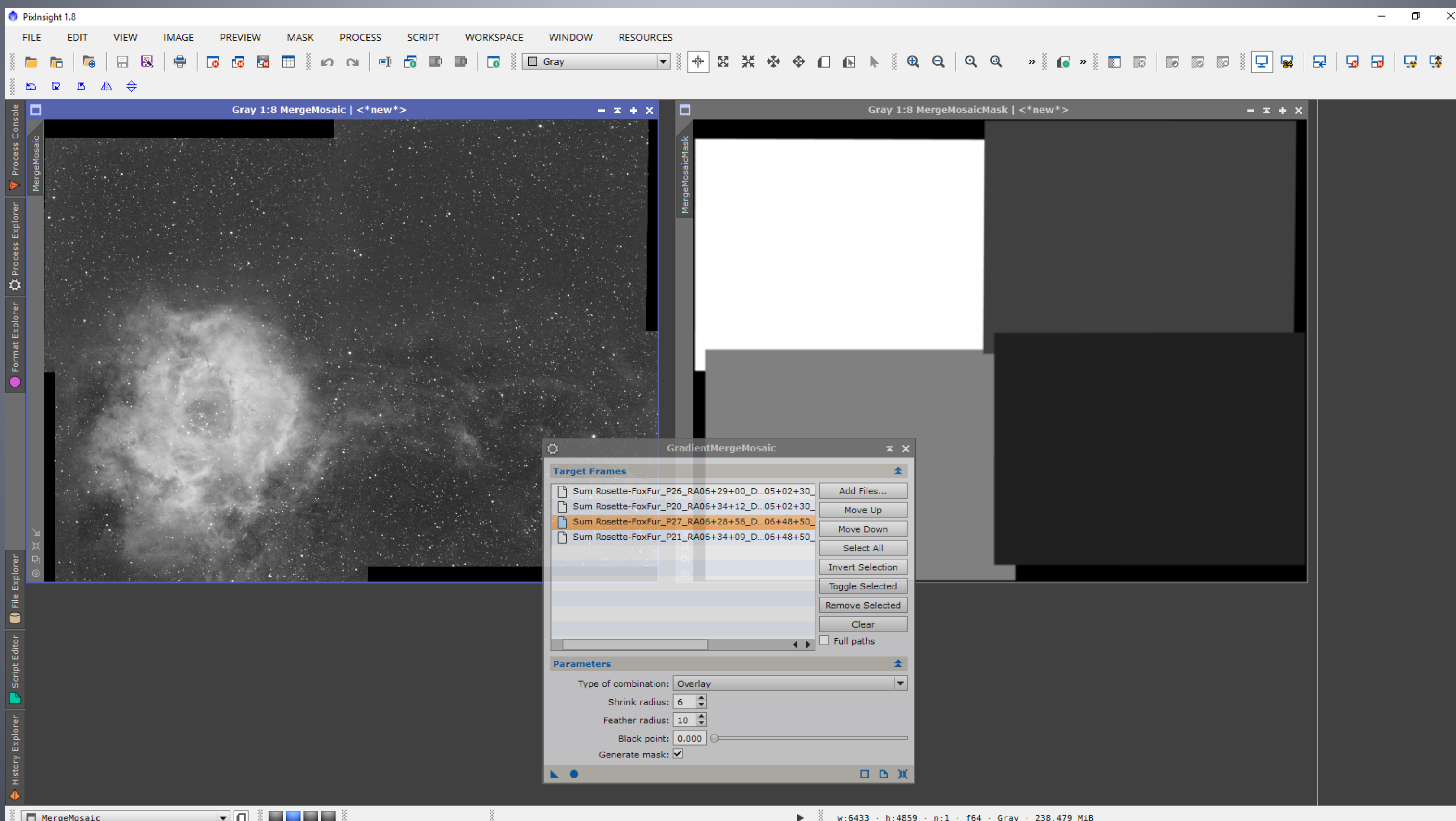
Creating wide-field mosaics
Mosaic stitching

- Sometimes pinch artefacts might appears on the merged mosaic
- Pinch artefacts are generated by bright stars located near the edge of two or more tiles
- They can be removed or attenuated by increasing the GMM parameters shrink and feather radius



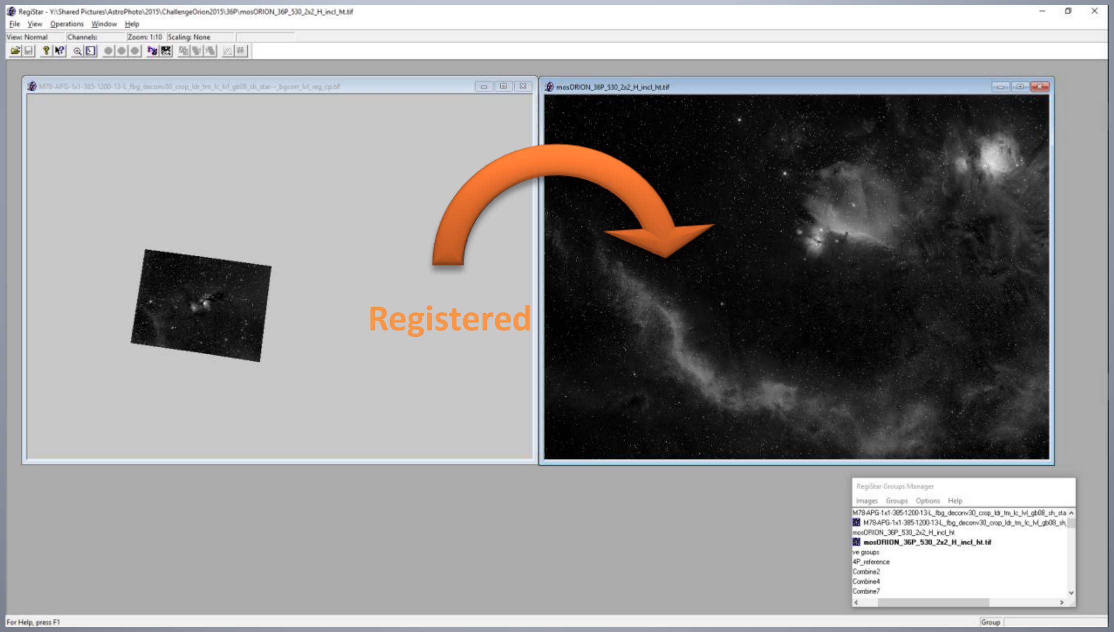
Creating wide-field mosaics
Mosaic stitching

- With a shrink radius at 6 and feather radius at 10 the pinch artefact has been completely removed



Creating wide-field mosaics
Mosaic stitching

- Once all mosaic monochromatic frames are seamlessly combined, they must be registered together in order to use them from creating the luminance and the chrominance master frames
- To do that registration, I usually use Registar because the registrations algorithms are very well adapted for that job but PixInsight work well too



- Once all monochromatic master frames are properly registered, they must be converted to 16bit TIF image file format
- Why TIF? because TIF are natively compatible with PhotoShop

Cygnus Loop (6 panels mosaic)

Chapter 9: Creating luminance master frame

Composing advanced LRGB images in false colors
Creating luminance master frame

- The luminance master frame is very important to bring out the faint structural details into the image

- It's very important to carefully process it in order to maximize the quality of the final image

- To create the luminance master frame, I mostly use the H-alpha narrowband data as a background data because it allows to reveal small structural details

- To improve the details on my luminance master frame, I usually add additional data such as
  - Broadband luminance or RGB
  - Narrwoband OIII and SII
  - Sometimes NIR

Composing advanced LRGB images in false colors
Creating luminance master frame

- Depending on the gas distribution inside the nebula, H-alpha data will not allow to reveal the entire body of the nebula because the light coming from those areas is emitted in other bandwidth
  - In this case, the luminance master frame must be created by bringing OIII and SII data to H-alpha

- To combine all available data into the luminance master frame, I derived a method developed by Rogelio Bernal Andero in the book (Lessons from the Masters - Robert Gendler)

- This method allows to split an image in two separate parts : one with large scale structures (LSS) and another one with small scale structures (SSS)

- To improve the SNR of the luminance master frame, the H-alpha, OIII and SII images can be combined with the following formula :
  - LSS(H-a) + LSS(OIII) + LSS(SII) = LSS(HOS)
  - LSS(HOS) + SSS(H-a) = Luminance

NOTE : Using only small scale details of H-alpha allows to do not add additional noise to the luminance.

Composing advanced LRGB images in false colors

Creating luminance master frame

- If you have broadband RGB data you can also combine them into the luminance master frame with the following formula:
  - LSS(H-a) + LSS(OIII)xW(OIII) + LSS(SII)xW(SII) + LSS(R)xW(R) + LSS(G)xW(G) + LSS(B)xW(B) = LSS(HOSRGB)
  - LSS(HOSRGB) + SSS(H-a) = Luminance

  W() is the weight applied to one monochromatic master frame

- If you have broadband luminance data you can also combine them into the luminance master frame with the following formula:
  - LSS(H-a) + LSS(OIII)xW(OIII) + LSS(SII)xW(SII) + LSS(L)xW(L) = LSS(HOSL)
  - LSS(HOSL) + SSS(H-a) = Luminance

  W() is the weight applied to one monochromatic master frame

  NOTE : Using only small scale details of H-alpha allows to do not add additional noise to the luminance.

Composing advanced LRGB images in false colors
Creating luminance master frame

- If OIII data contains good small scale details (e.g. Veil nebula). You can bring them into the luminance master frame with the following formula :
  - LSS(H-a) + LSS(OIII)xW(OIII) + LSS(SII)xW(SII) = LSS(HOS)
  - SSS(H-a) + SSS(OIII)xW(OIII) = SSS(HO)
  - LSS(HOS) + SSS(HO) = Luminance

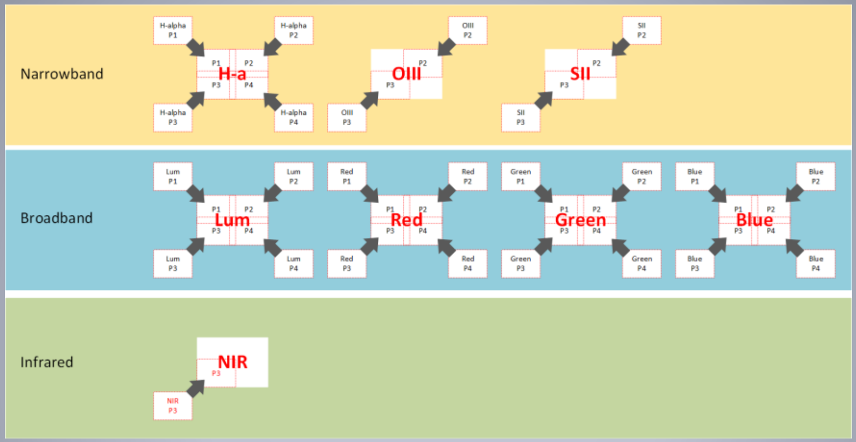
  W() is the weight applied to one monochromatic master frame

- If SII data contains good small scale details (e.g. Veil nebula). You can also bring them into the luminance master frame, with the following formula :
  - LSS(H-a) + LSS(OIII)xW(OIII) + LSS(SII)xW(SII) = LSS(HOS)
  - SSS(H-a) + SSS(OIII)xW(OIII) + SSS(SII)xW(SII) = SSS(HOS)
  - LSS(HOS) + SSS(HOS) = Luminance

  W() is the weight applied to one monochromatic master frame

NOTE : Using small scale data of OIII and/or SII is sometimes counter productive because depending on the object it brings few details and a lot more noise.

Composing advanced LRGB images in false colors
Creating luminance master frame



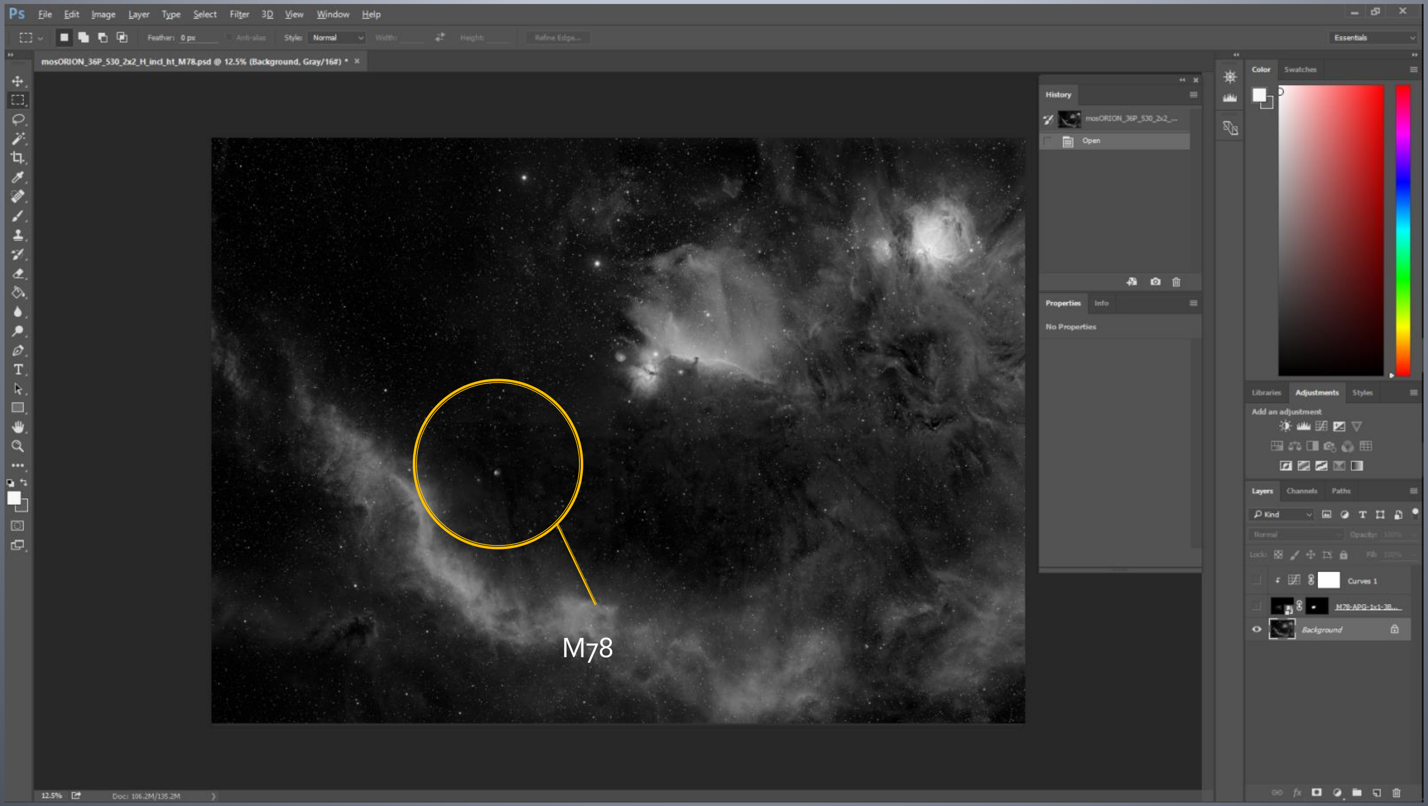
Asymmetric stitching workflow

- While stitching, if we have used an asymmetric workflow all monochromatic mosaic master frames does not cover the whole mosaic field
- In that case the monochromatic mosaic master frames must be properly added to the luminance master frame by using masks and curves

Composing advanced LRGB images in false colors

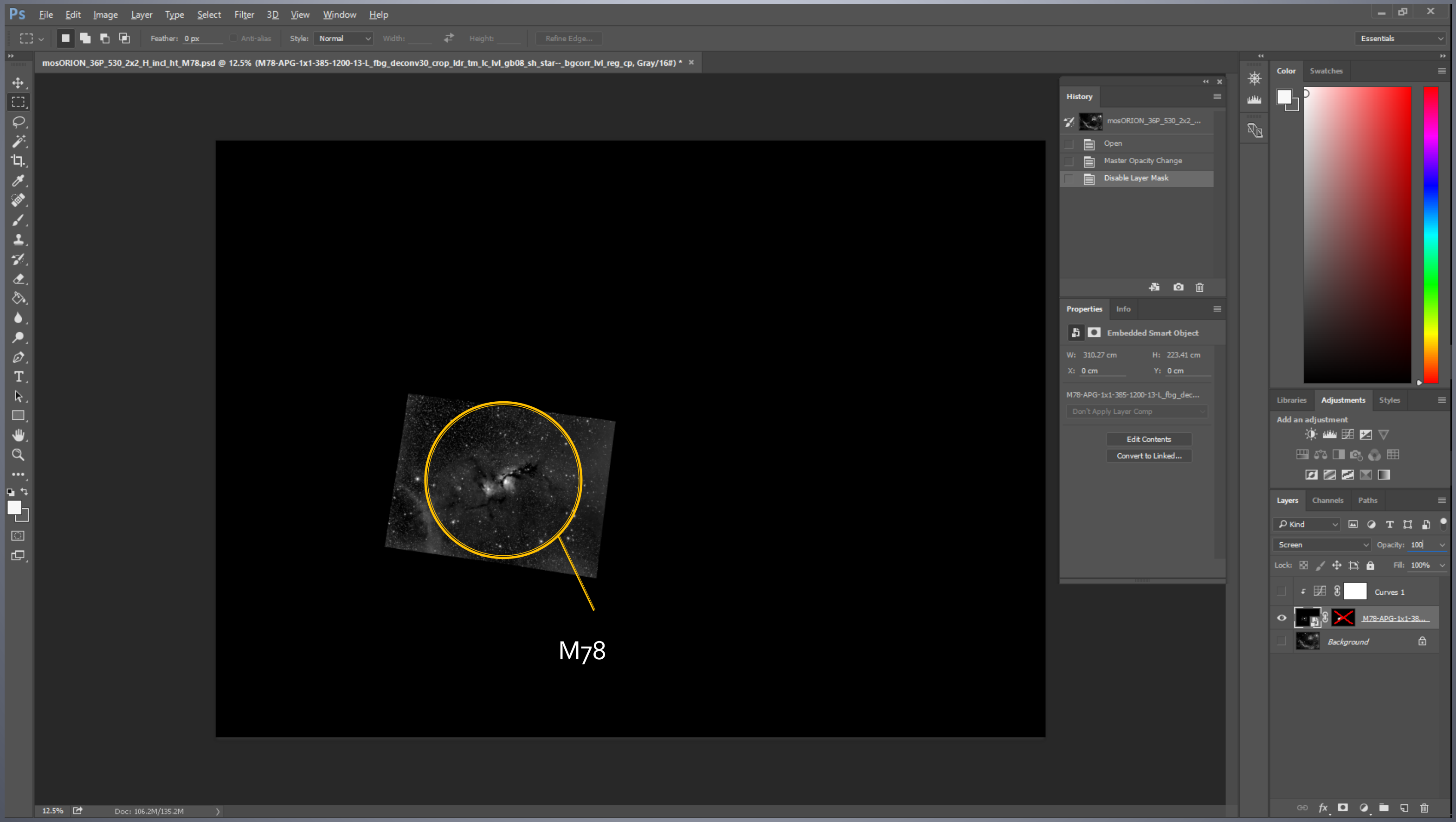
Creating luminance master frame

- In H-alpha data M78 is almost invisible
- This is because M78 is a reflection nebula and H-alpha filter only works with emission nebula
- To make M78 visible in the luminance master frame, I must combine the data captured with broadband filters with the H-alpha



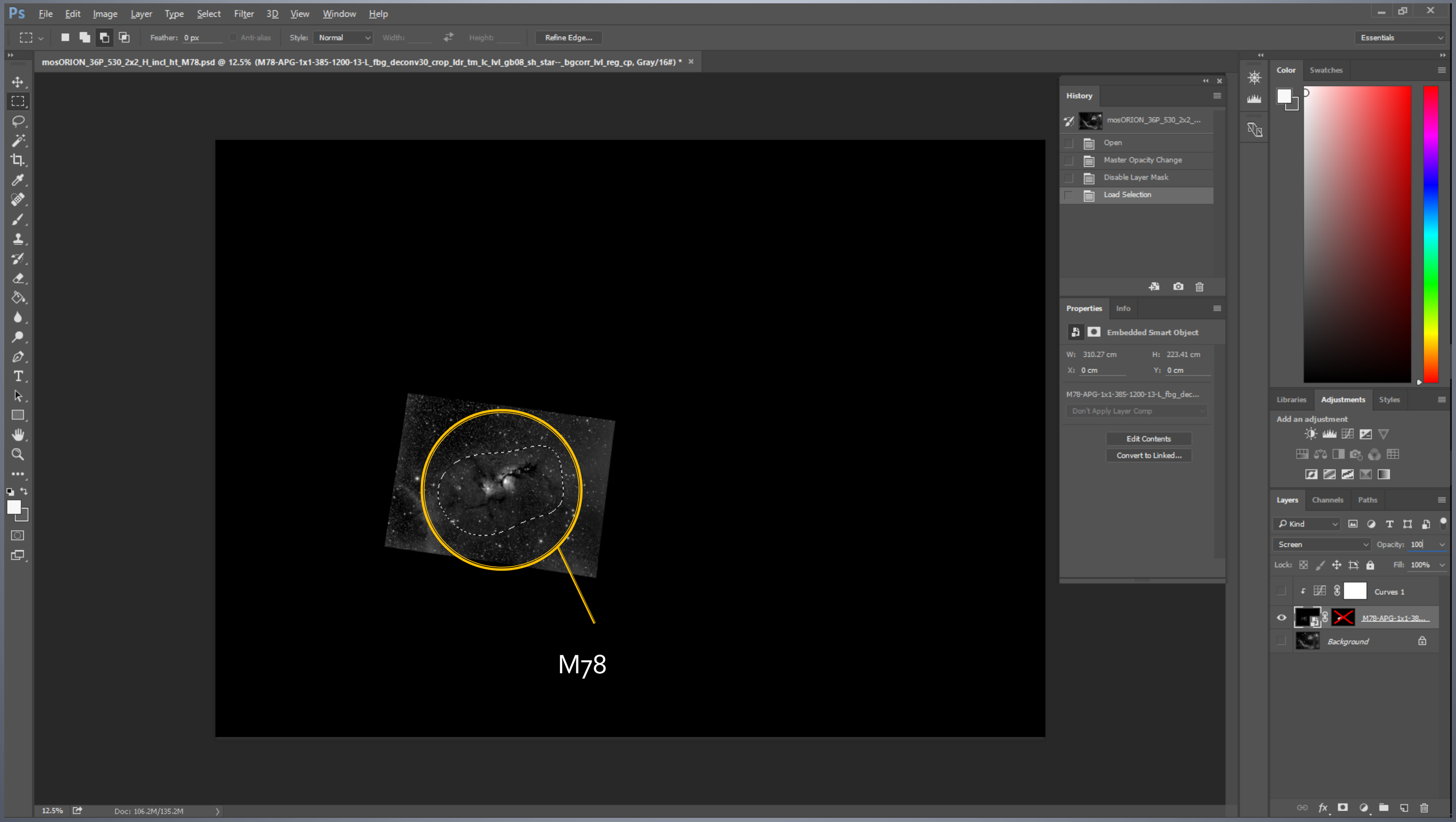
Composing advanced LRGB images in false colors
Creating luminance master frame

- To do that, I load the broadband master frame of M78 on top of my luminance master frame
  - The frame containing M78 must have been previously registered with the luminance master frame



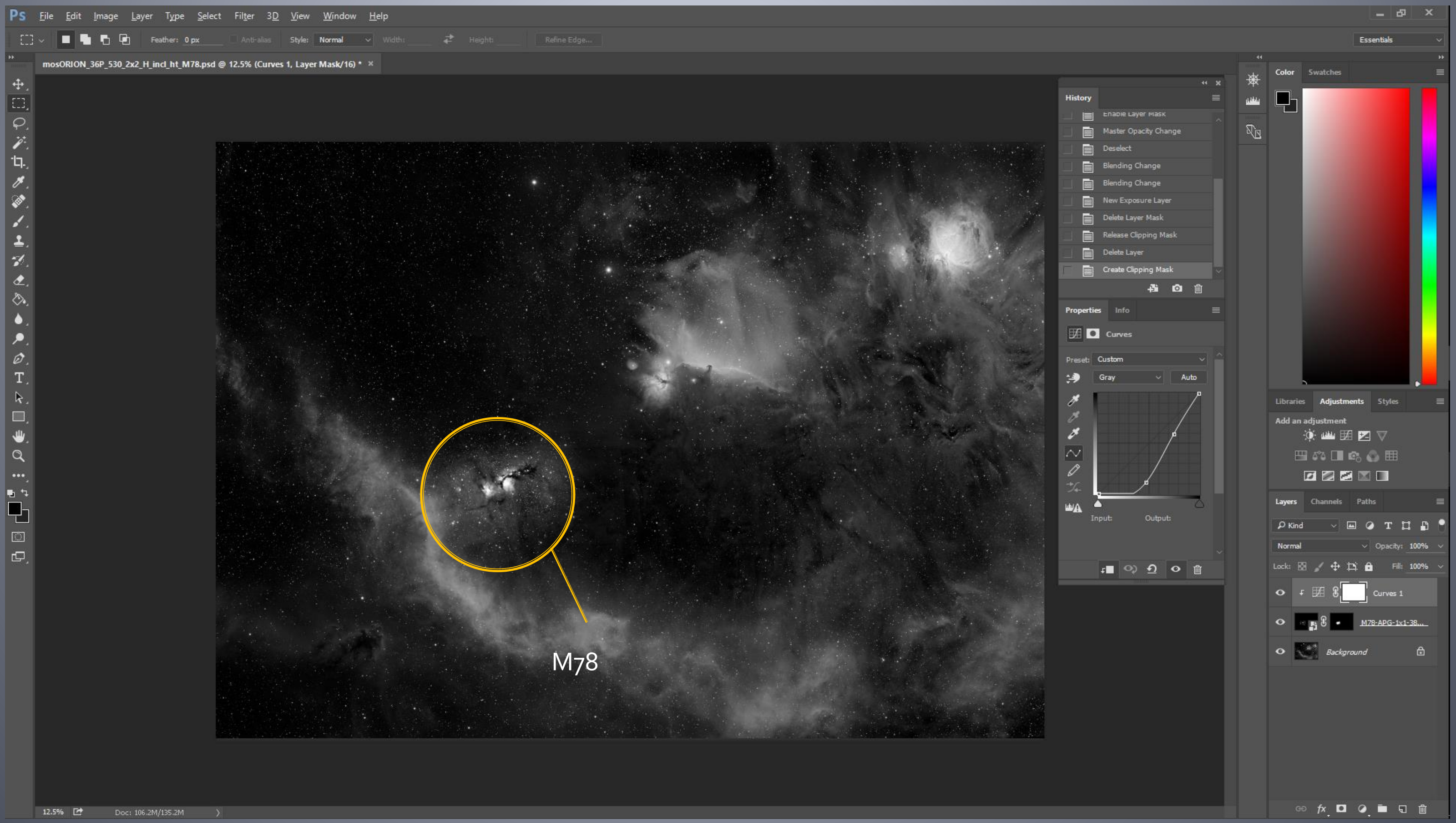
Composing advanced LRGB images in false colors
Creating luminance master frame

- Then I draw a mask that surround M78
  - I use feather function to soften the mask



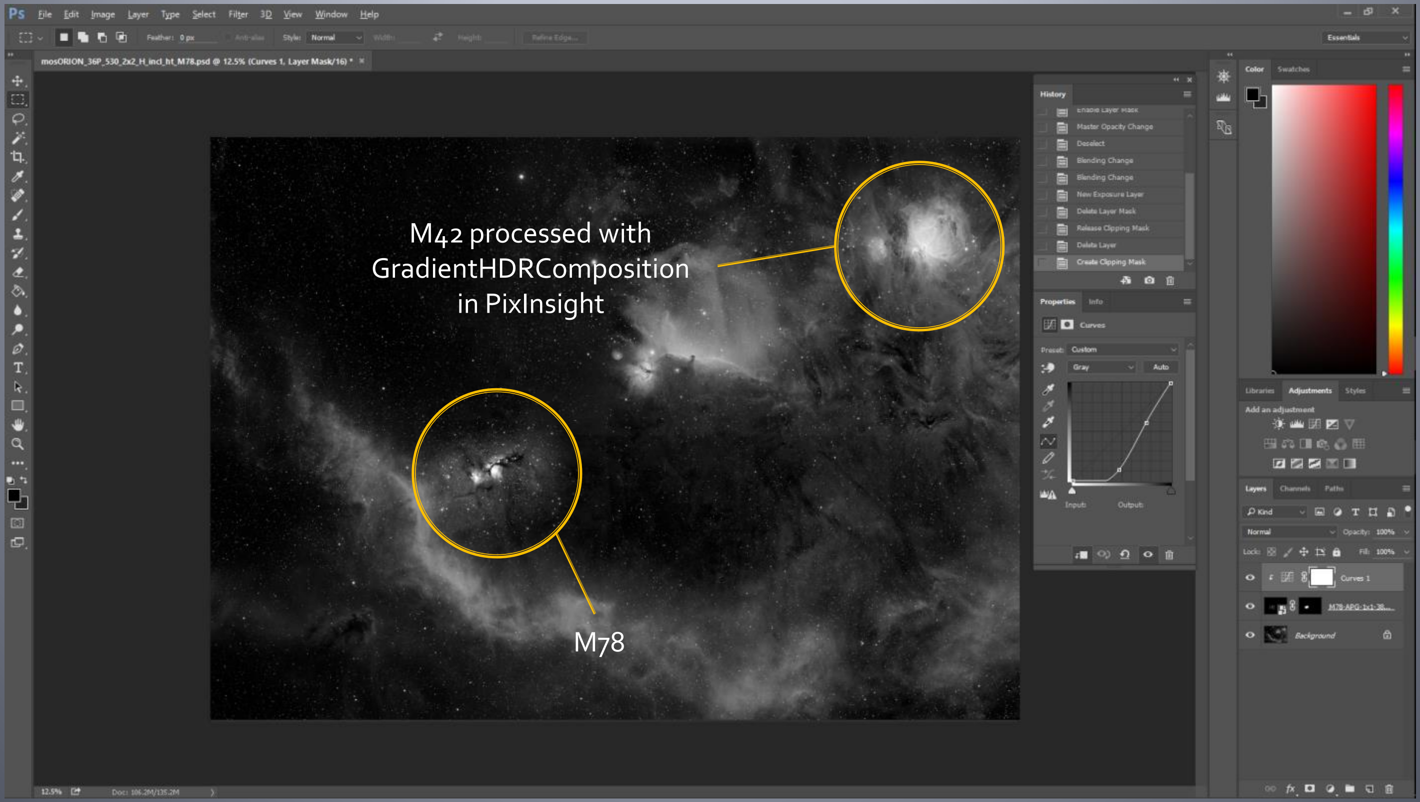
Composing advanced LRGB images in false colors
Creating luminance master frame

- I add curve as clipping mask of M78 layer and I play with curves to adjust M78 against the master luminance frame



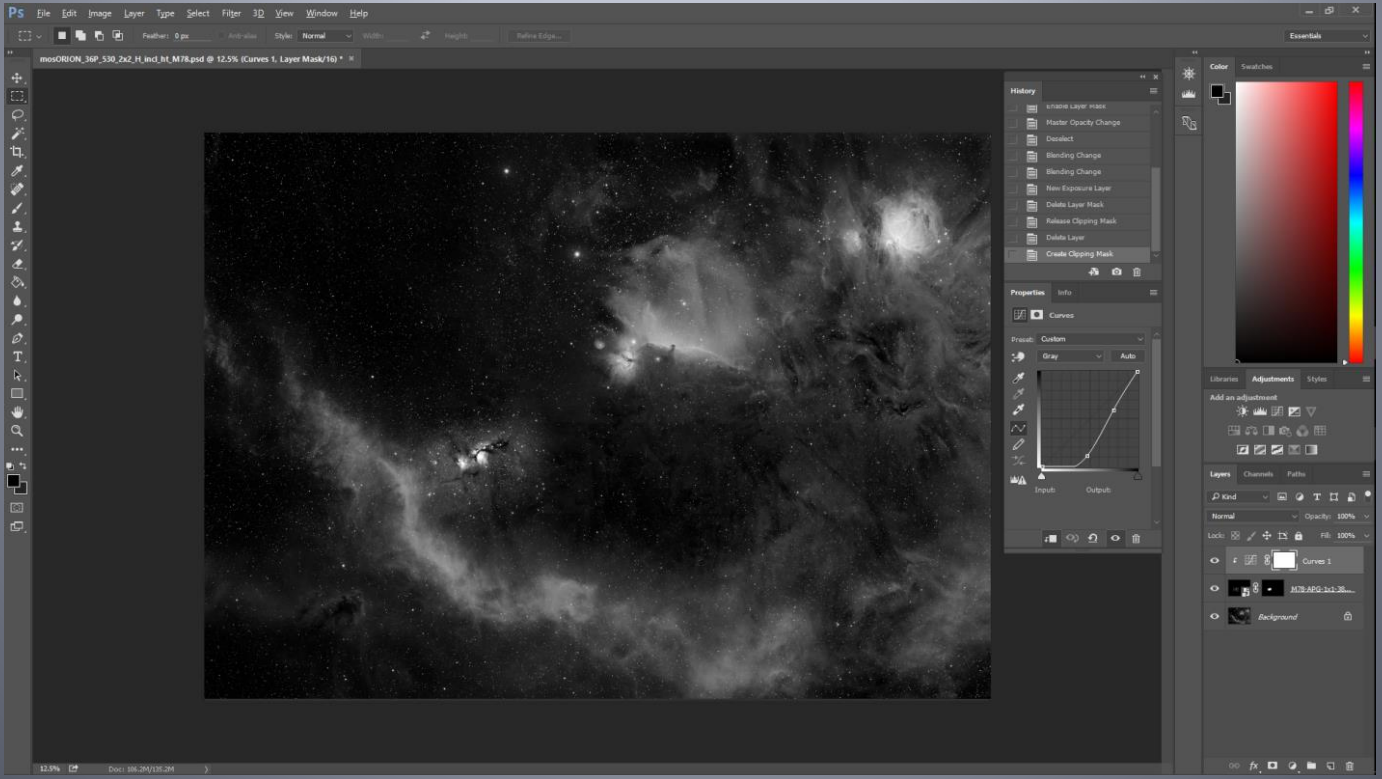
Composing advanced LRGB images in false colors
Creating luminance master frame

- Repeat the same workflow to merge all monochromatic master frame into the luminance master frame
  - For example: to avoid saturation of M42, I have used the same workflow to include a HDR processed version of M42 into my master luminance

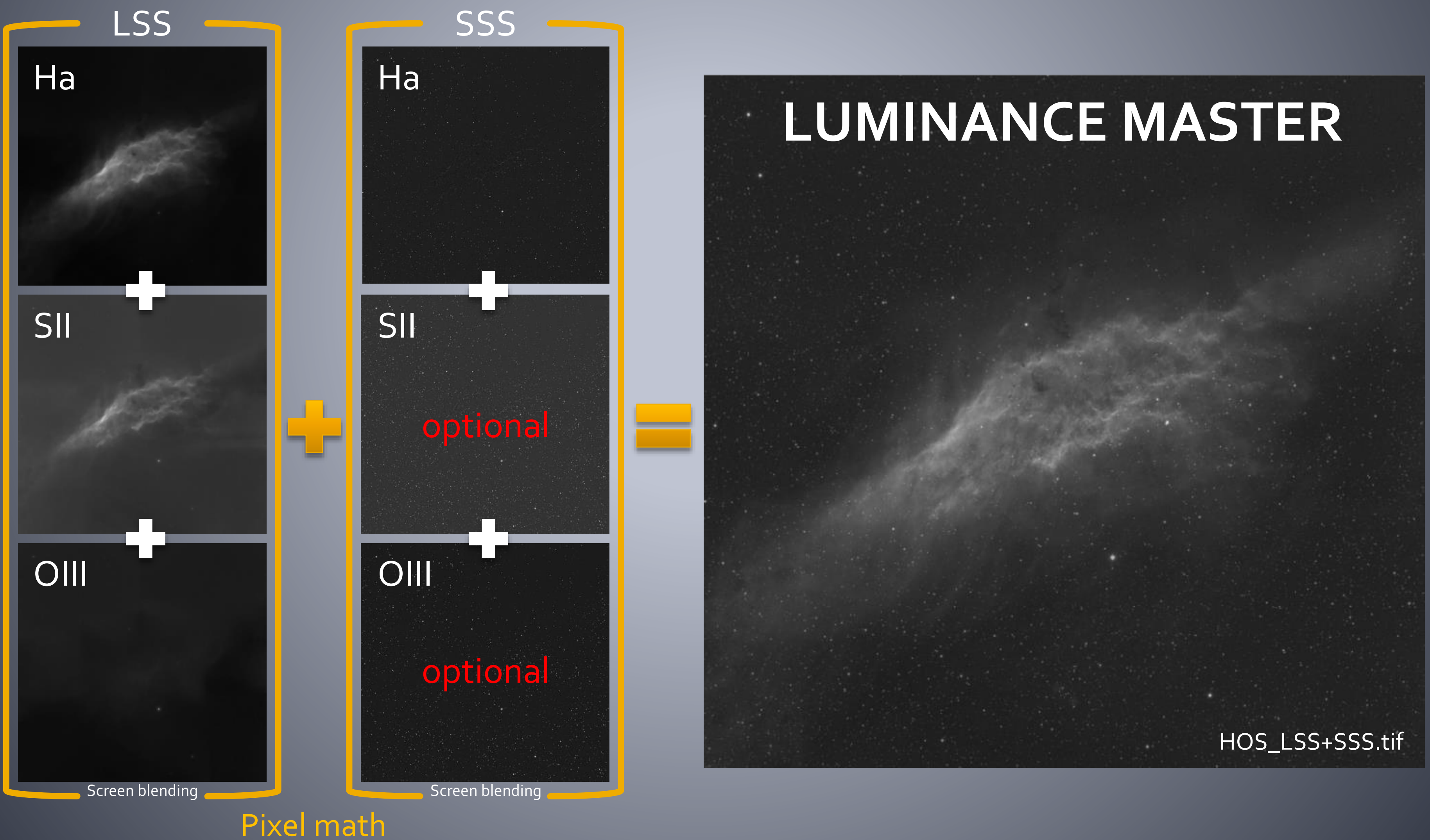


Composing advanced LRGB images in false colors
Creating luminance master frame

- This process allows to enriches the luminance by adding various data coming from different instruments, scales and sensors
  - When adding partial data to the luminance master frame, don’t forget to do the same on the chrominance master frames otherwise the added area will not be colored correctly during the final LRGB composition



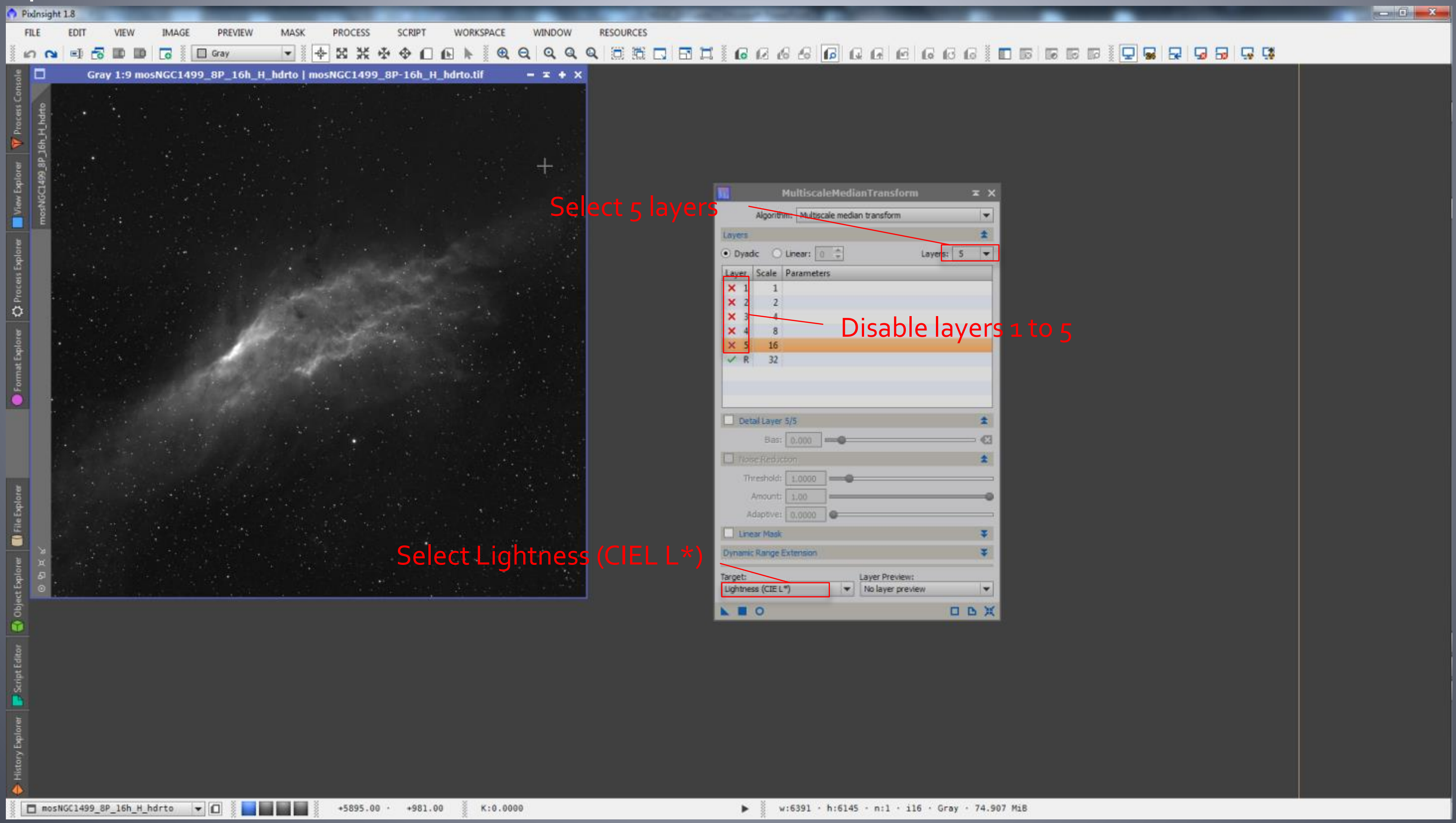
Composing advanced LRGB images in false colors
Creating luminance master frame



Composing advanced LRGB images in false colors

Creating luminance master frame

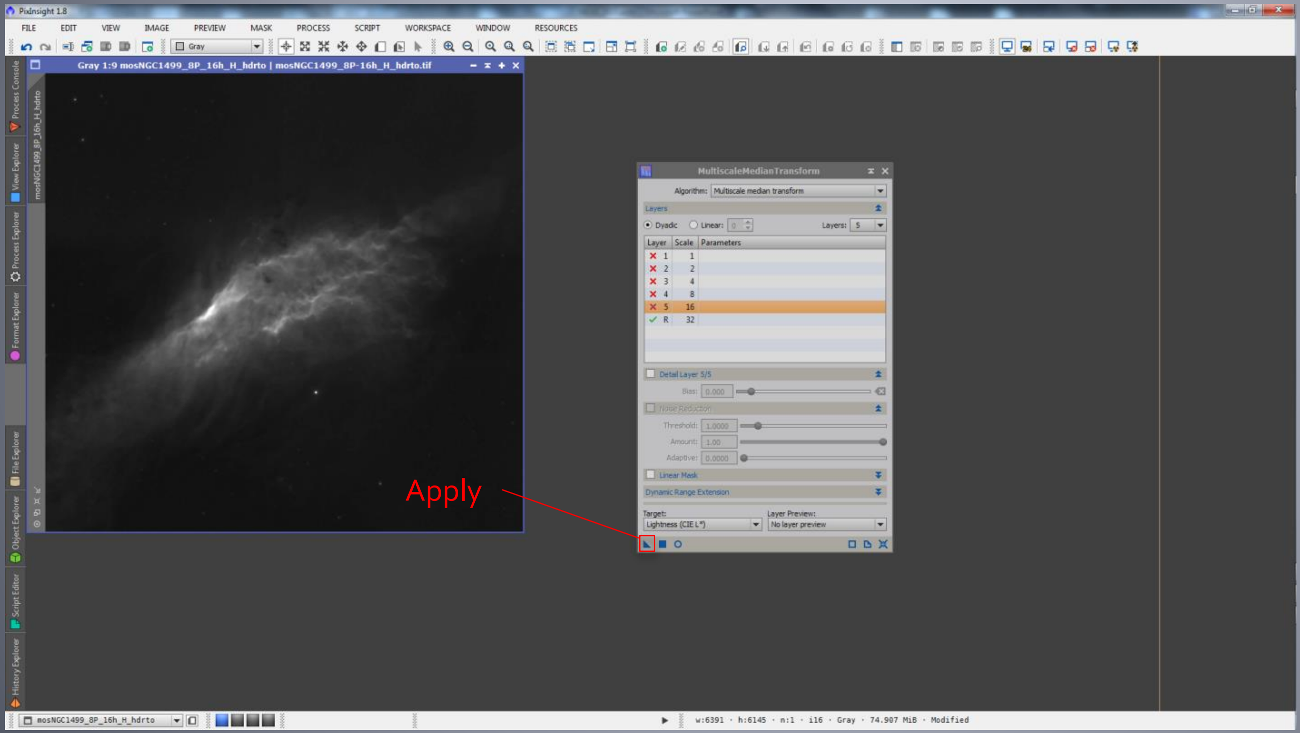
- Open the file mosNGC1499_8P-H.tif (original H-alpha image) in PixInsight
- Open MultiscaleMedianTransform



Composing advanced LRGB images in false colors
Creating luminance master frame

- Apply MultiscaleMedianTransform on the image

  NOTE : Small scale details and stars have been properly removed from the image



- Save the image to H-LSS.tif
- Repeat the process for original SII and OIII images

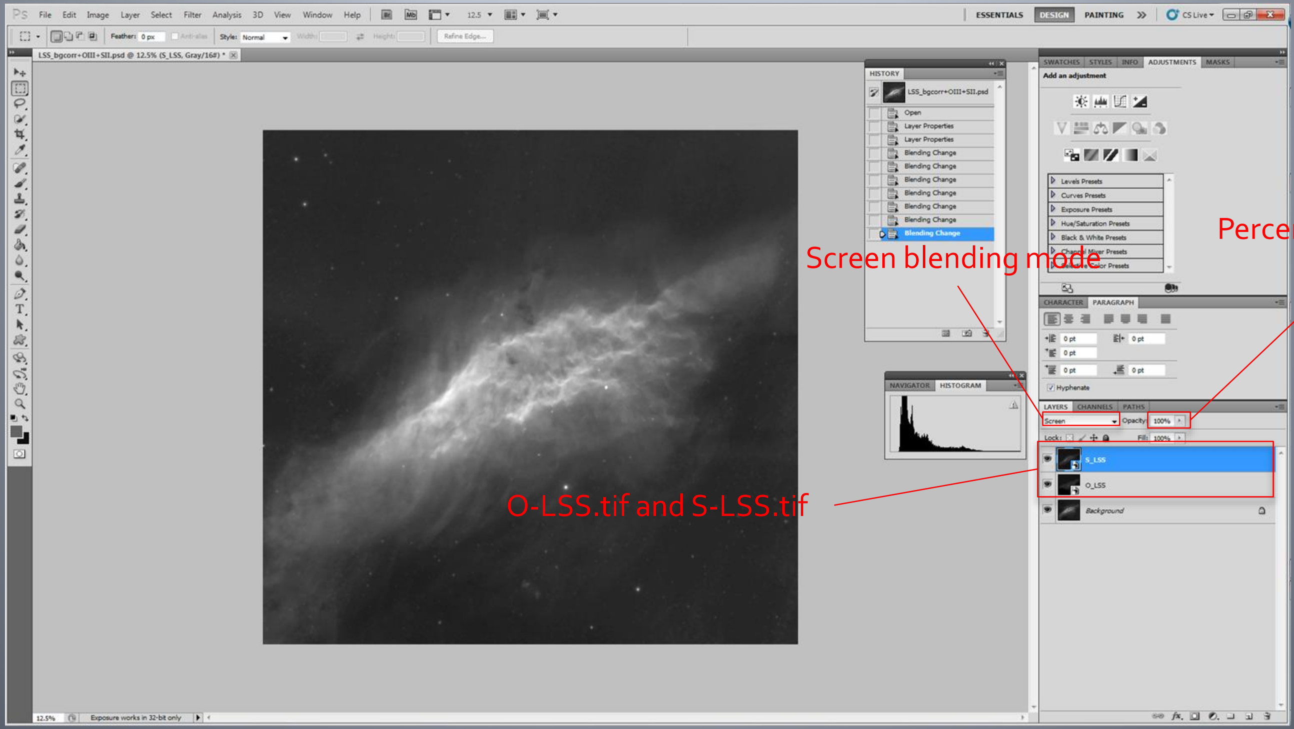
  NOTE : RGB data can also be used to improve the SNR.

Composing advanced LRGB images in false colors

Creating luminance master frame

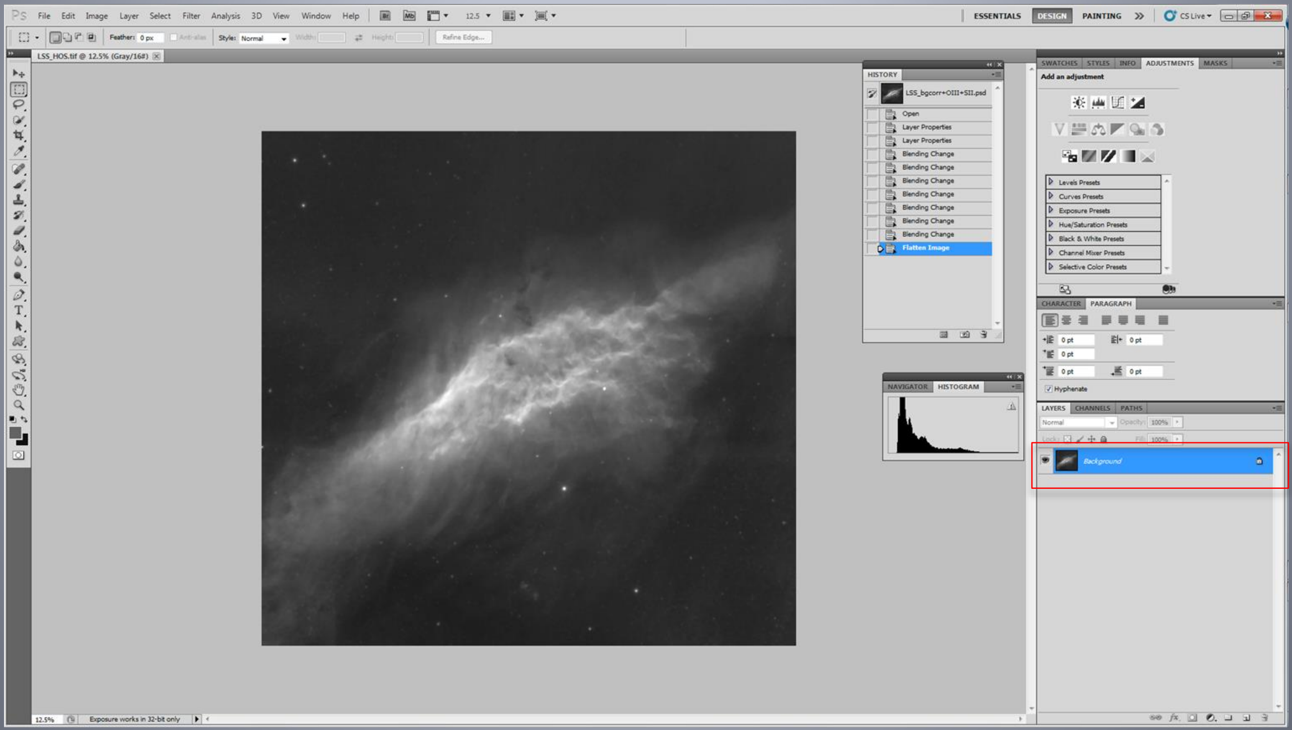
- Open file H-LSS.tif in Photoshop
- Place files O-LSS.tif and S-LSS.tif on top of the Background layer
- Choose Screen blending mode for both

NOTE : To equalize the amount of signal added by additional layer you can lower the percentage of opacity.



Composing advanced LRGB images in false colors
Creating luminance master frame

- Flatten the image
- Save the image to LSS_HOS.tif

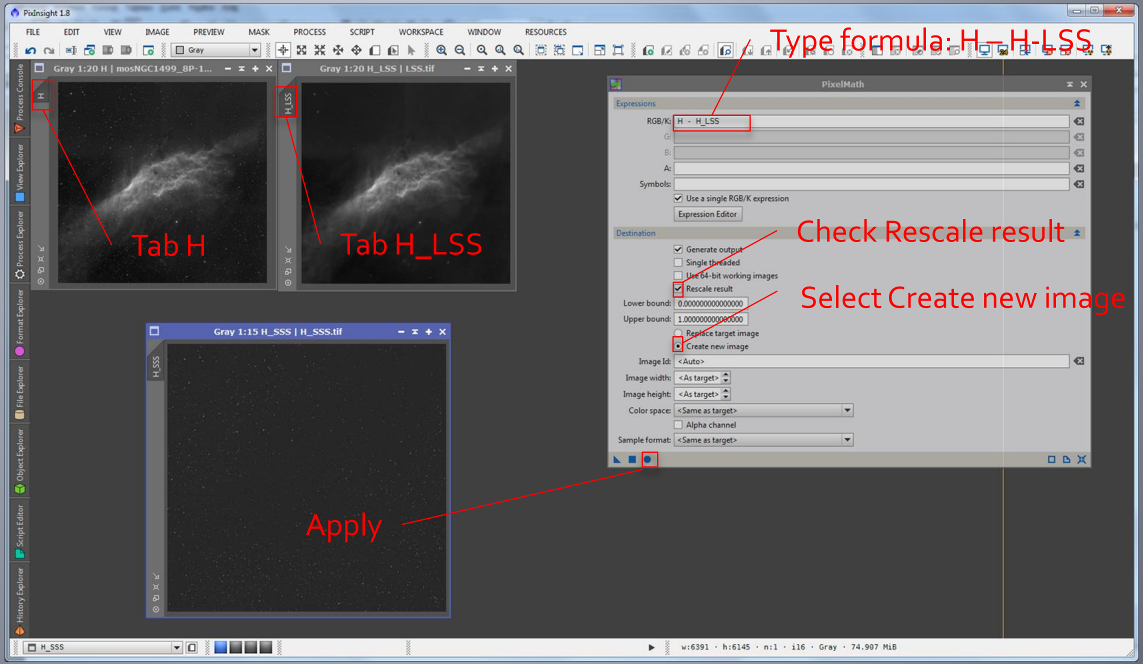


At this level the signal of all data is combined into a single image

Composing advanced LRGB images in false colors

Creating luminance master frame

- Go back to PixInsight
- Open the file mosNGC1499_8P-H.tif (original H-alpha image) and rename the tab H
- Open the file H-LSS.tif (H-alpha large scale structure)
- Open PixelMath

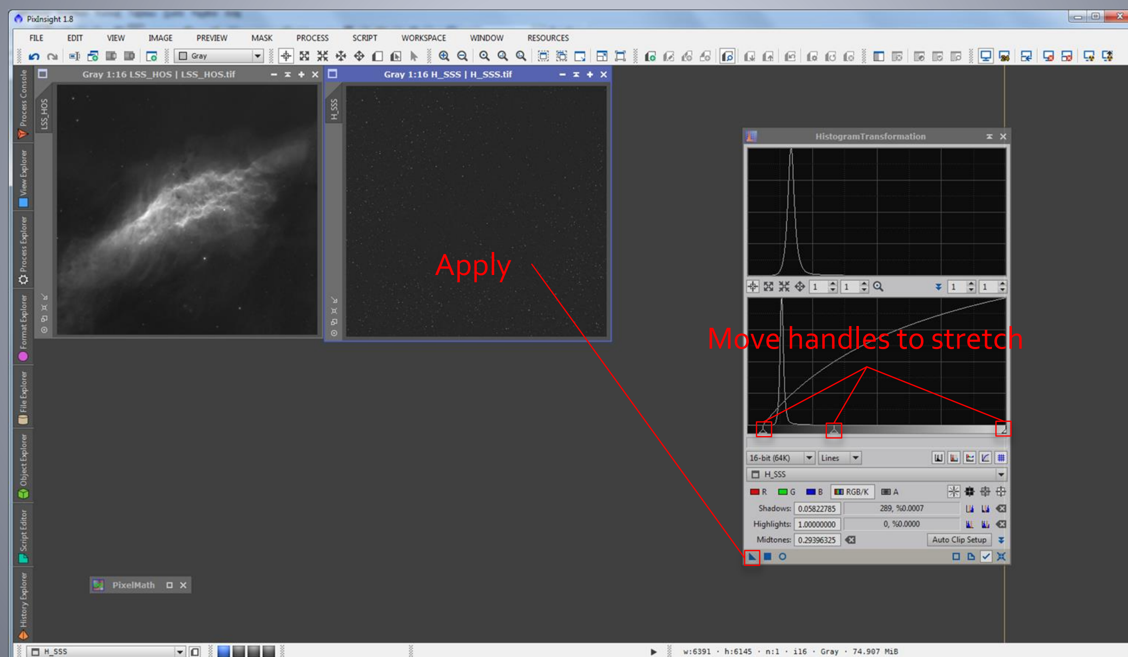


- Apply PixelMath

  NOTE : That the newly created image contain only small scale details including stars
- Save the image to H-SSS.tif

Composing advanced LRGB images in false colors
Creating luminance master frame

- Open files LSS_HOS.tif and H_SSS.tif
- Open HistogramTransformation

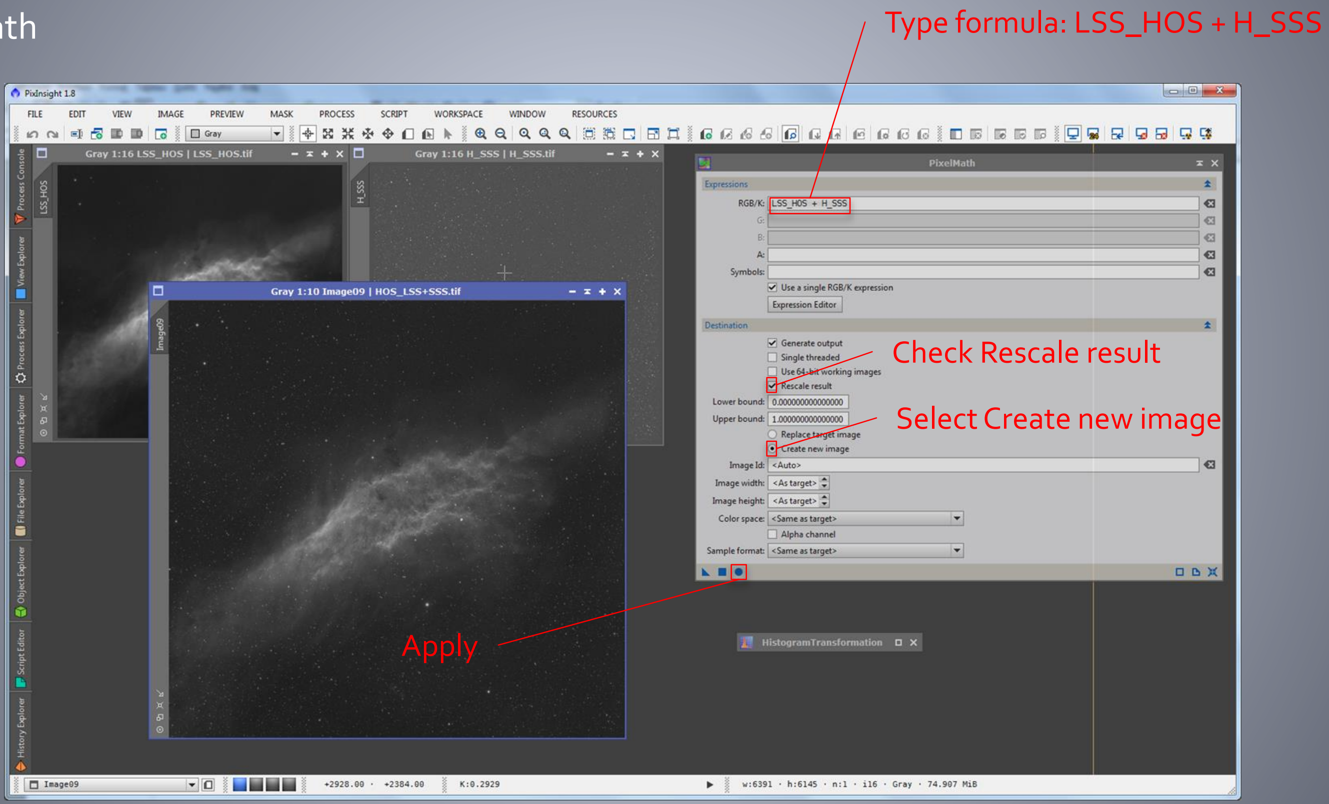


- Stretch the H_SSS image to increase the signal of small scale details

NOTE: Take care to do not crop the peak

Composing advanced LRGB images in false colors
Creating luminance master frame

- Open PixelMath



- Apply PixelMath

  NOTE : If the details are not visible enough then close the new image, undo HistrogramTransform on H_SSS image and go one step backward to make a better stretching
- Save the image to HOS_LSS+SSS.tif

Composing advanced LRGB images in false colors

Creating luminance master frame

At this level the image contains the small structural details of H-alpha embedded with the large scale structures of all available data

Soul and heart nebulae (8 panels mosaic)

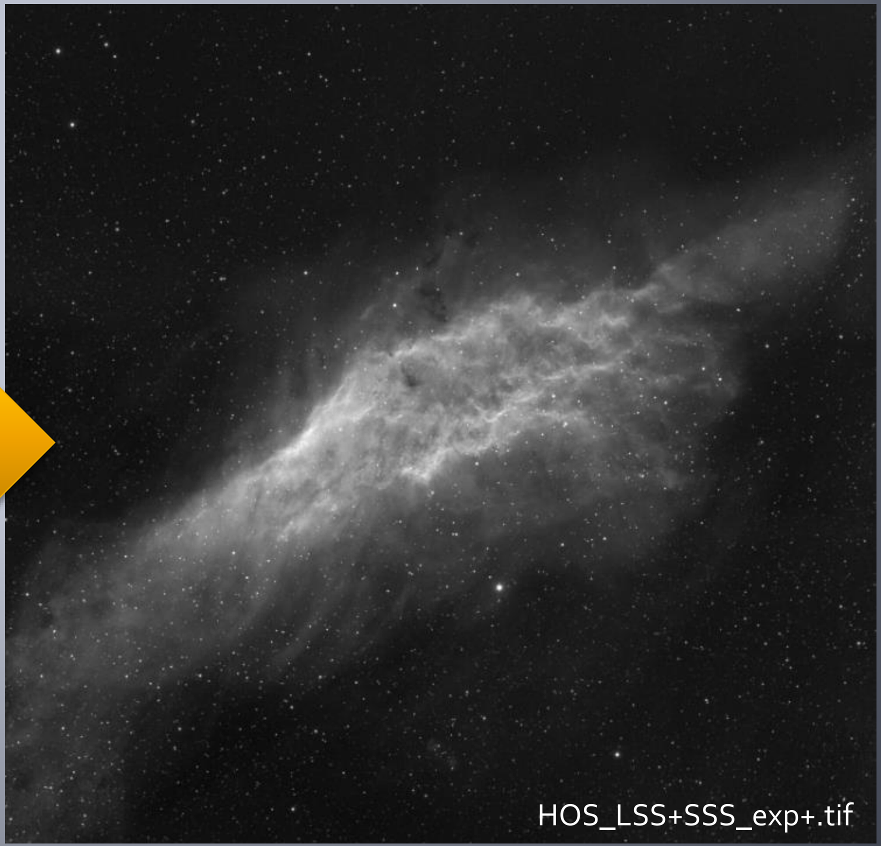
Chapter 10: Bringing out the structural details

Composing advanced LRGB images in false colors

Bringing out the structural details

Using mask to increase exposure of the nebula without increasing the background noise

BEFORE



AFTER

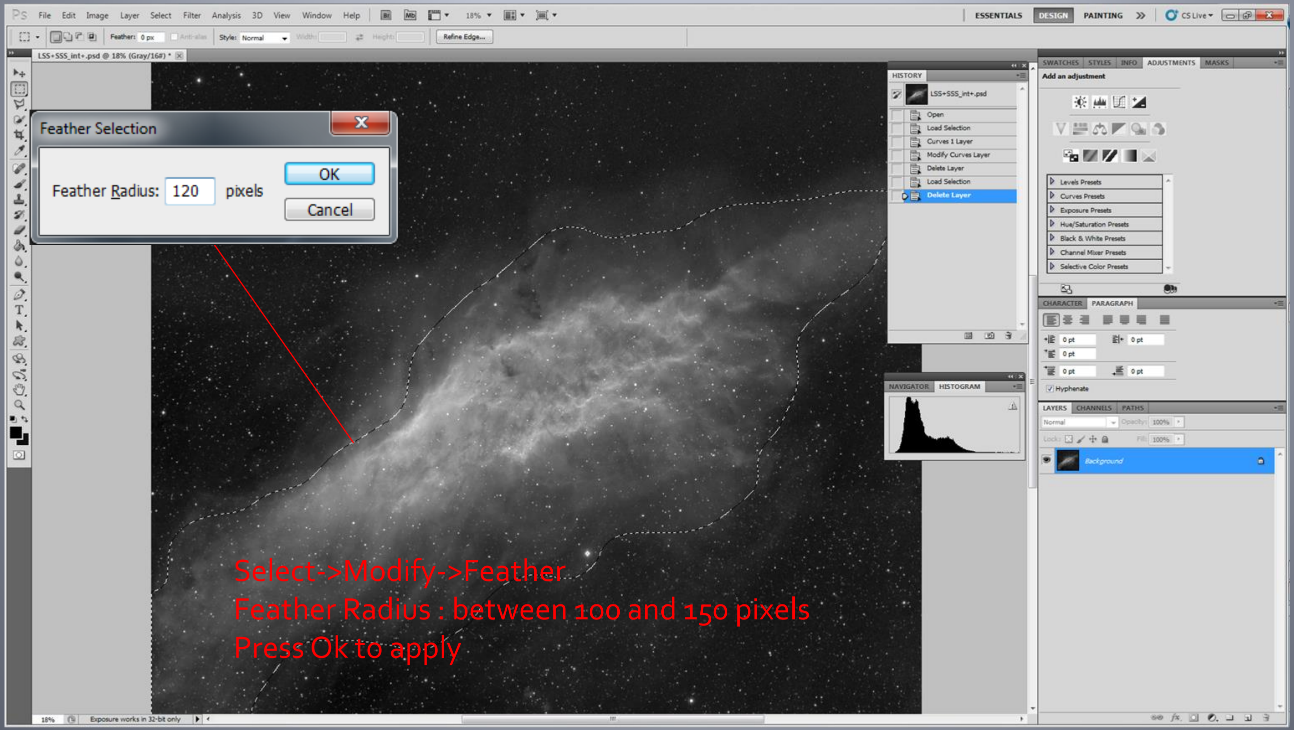
Composing advanced LRGB images in false colors

Bringing out the structural details

Using mask to increase exposure of the nebula without increasing the background noise

- Open PhotoShop
- Open the file HOS_LSS+SSS.tif
- Select the nebula with the lasso tool

NOTE: Take care to do not select the background



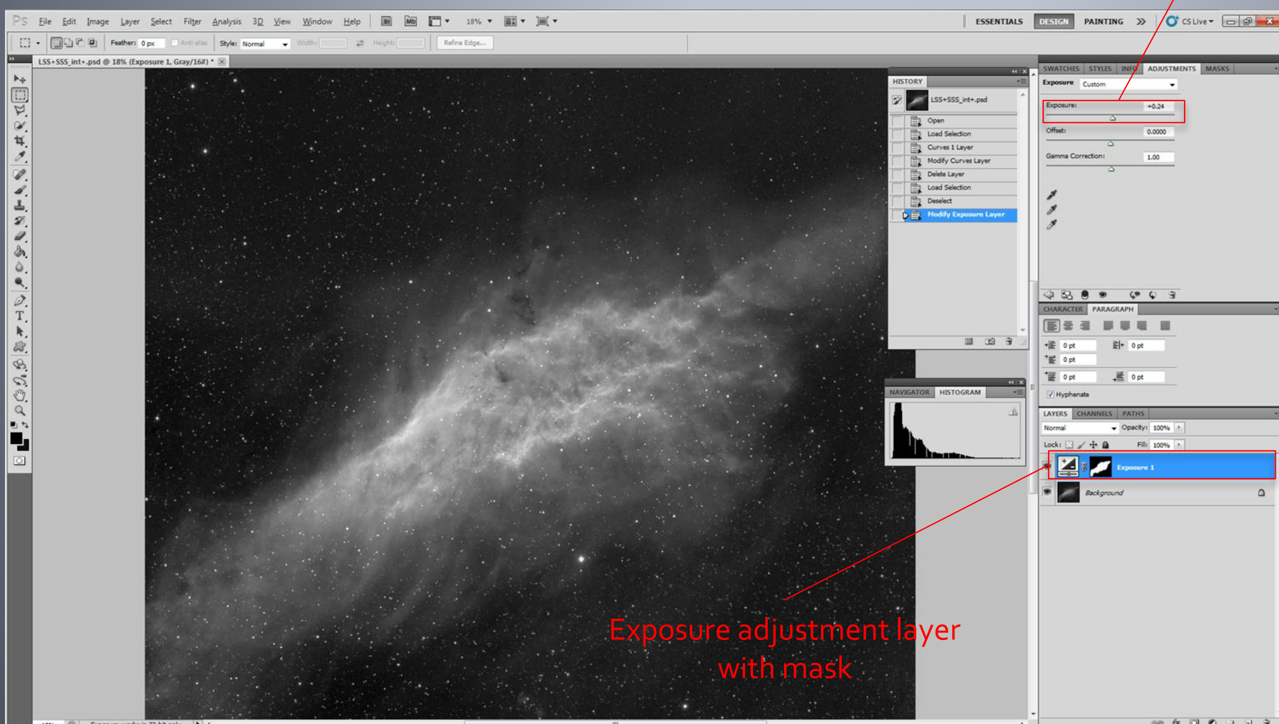
Composing advanced LRGB images in false colors

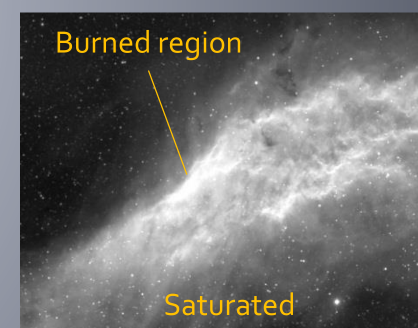
Bringing out the structural details

Using mask to increase exposure of the nebula without increasing the background noise

- Add Exposure Adjustment Layer with the previous selection as mask
  - Increase the exposure

NOTE : Take care to do not saturate



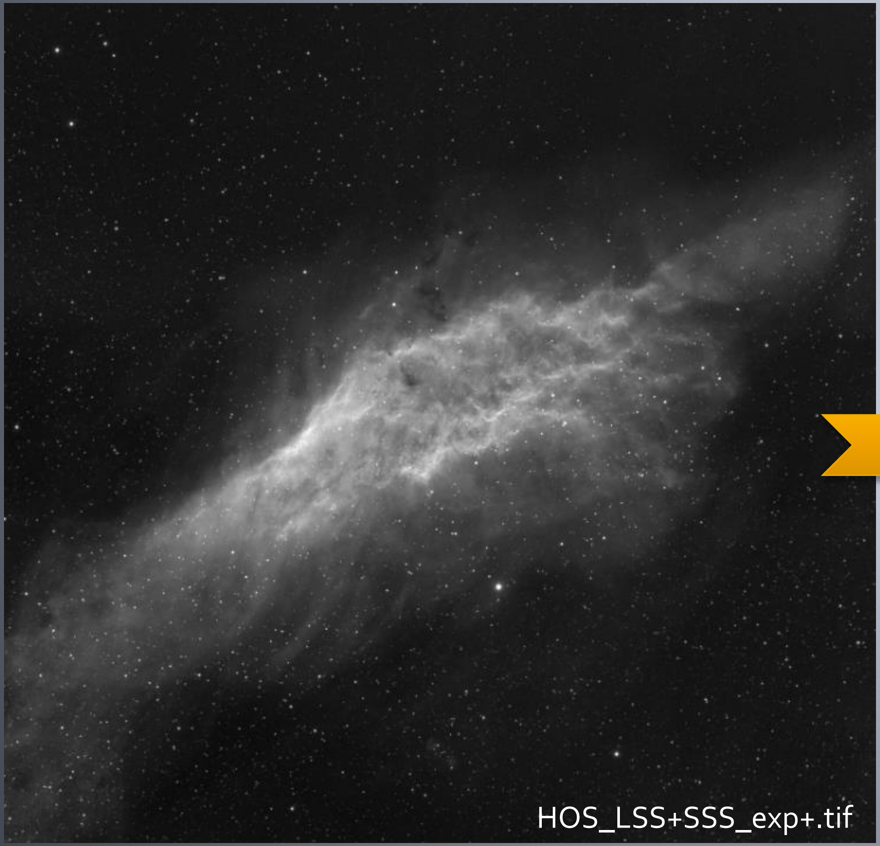


- Save the image to HOS_LSS+SSS_exp+.tif

Composing advanced LRGB images in false colors

Bringing out the structural details

Using shadow and highlight to emphasize the small structural details

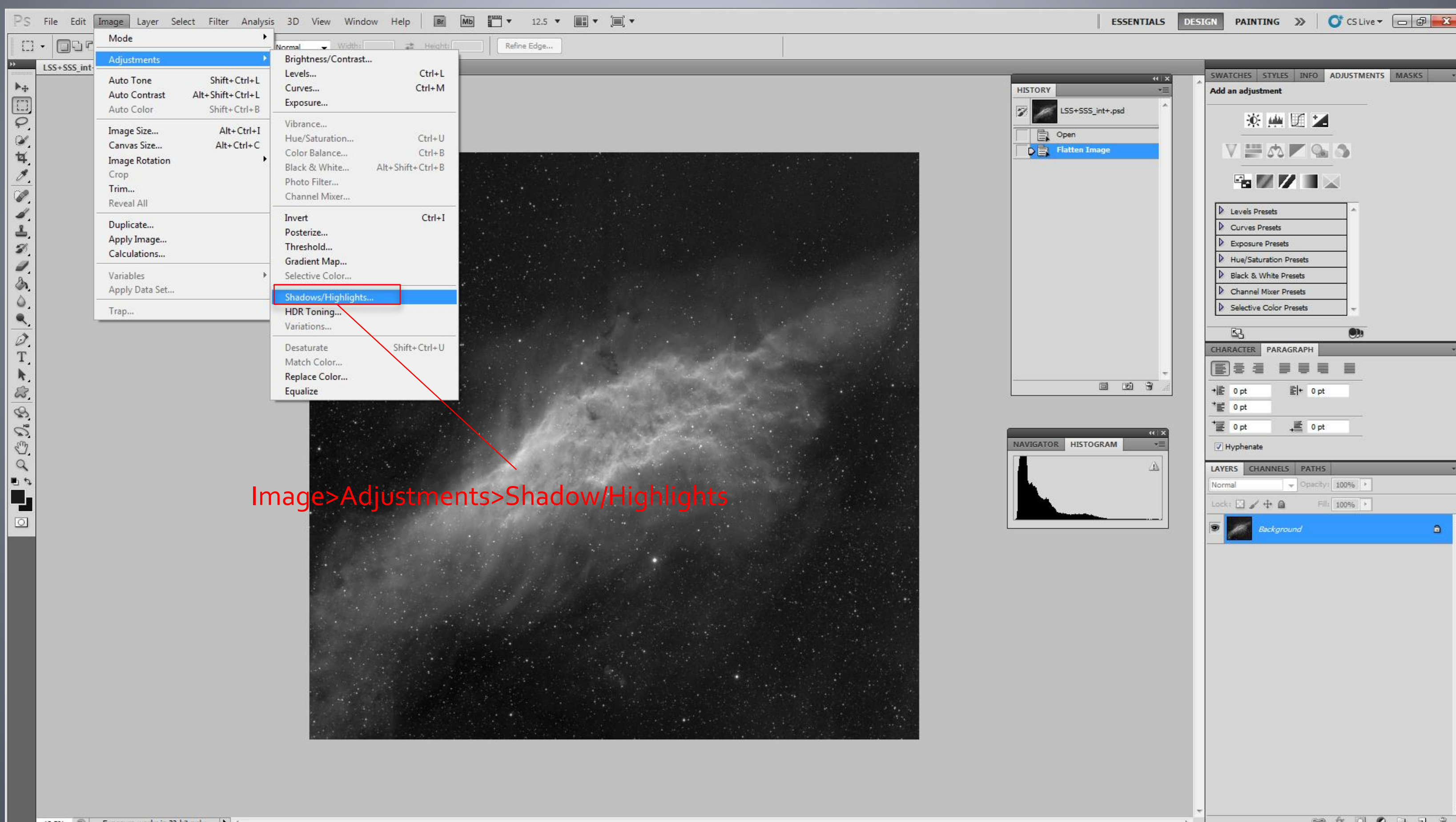


BEFORE

AFTER

Composing advanced LRGB images in false colors
Bringing out the structural details
Using shadow and highlight to emphasize the small structural details

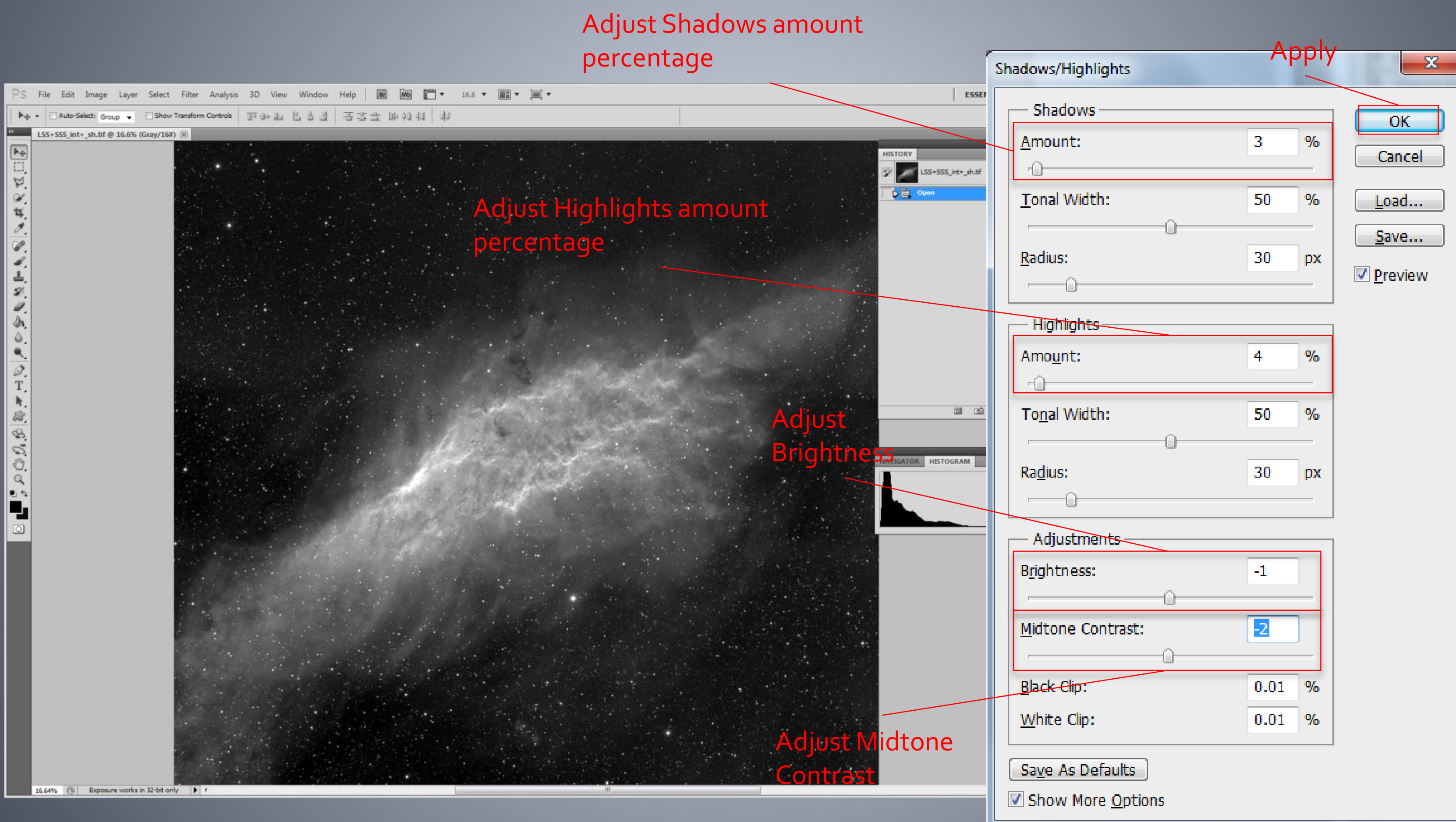
- Open file HOS_LSS+SSS_exp+.tif



Composing advanced LRGB images in false colors

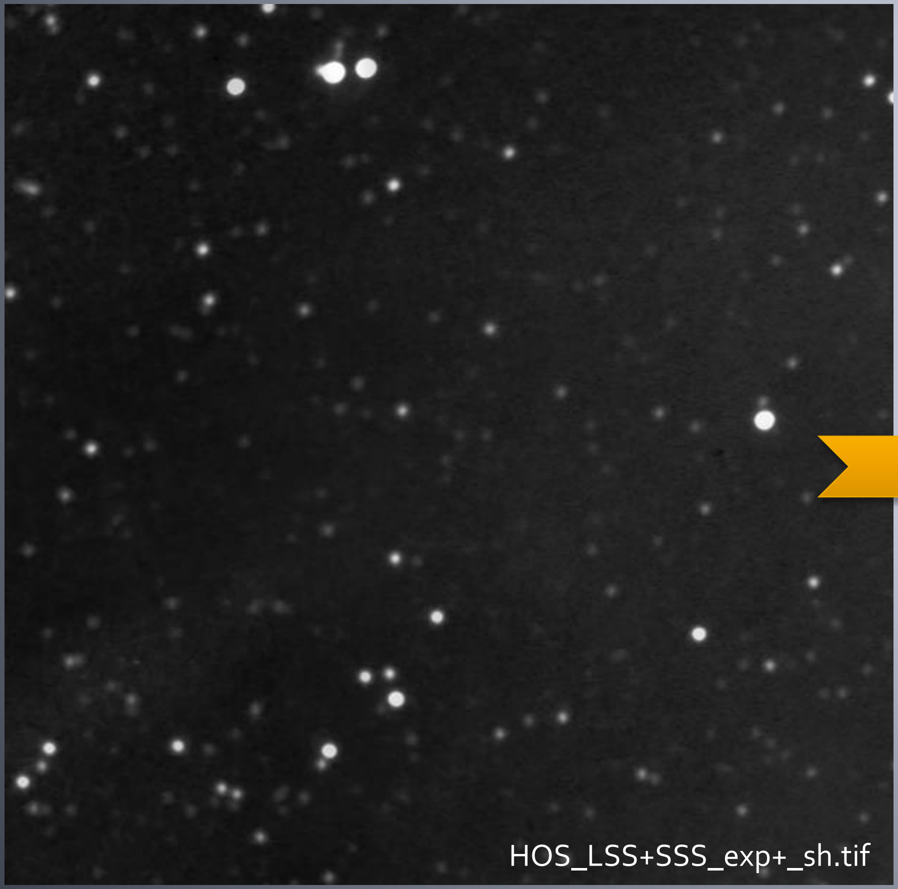
Bringing out the structural details

Using shadow and highlight to emphasize the small structural details



- Adjust Shadows/Highlights amounts until you get the expected result
- Save the image to HOS_LSS+SSS_exp+_sh.tif

Composing advanced LRGB images in false colors
Bringing out the structural details
Reducing noise



BEFORE

AFTER

Composing advanced LRGB images in false colors

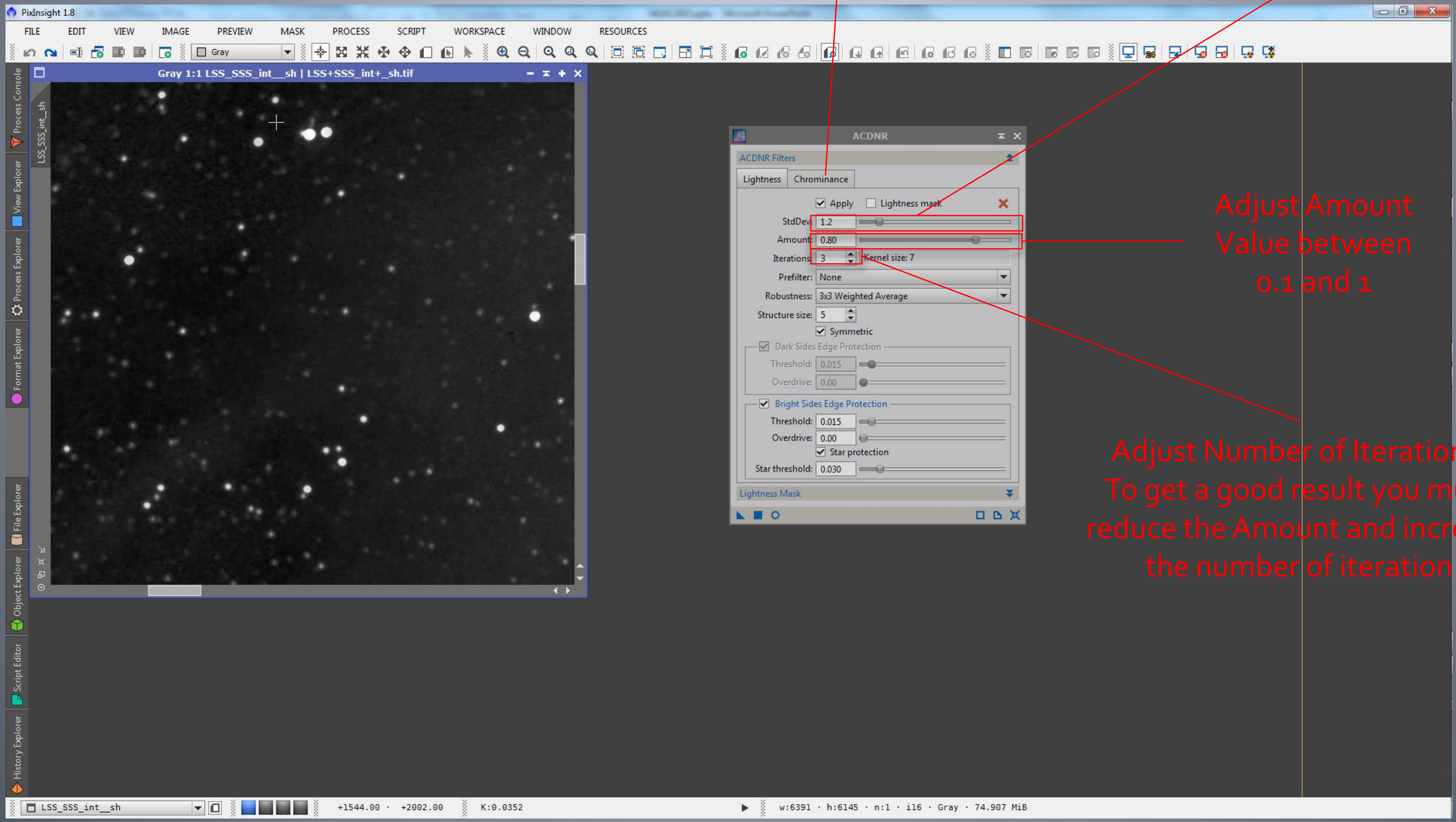
Bringing out the structural details

Reducing noise

- Open PixInsight
- Open HOS_LSS+SSS_exp+_sh.tif
- Open ACDNR

Uncheck Apply in Chrominance tab

Adjust StdDev
Value between 1 and 1.5 pixels are good to remove high-frequency noise



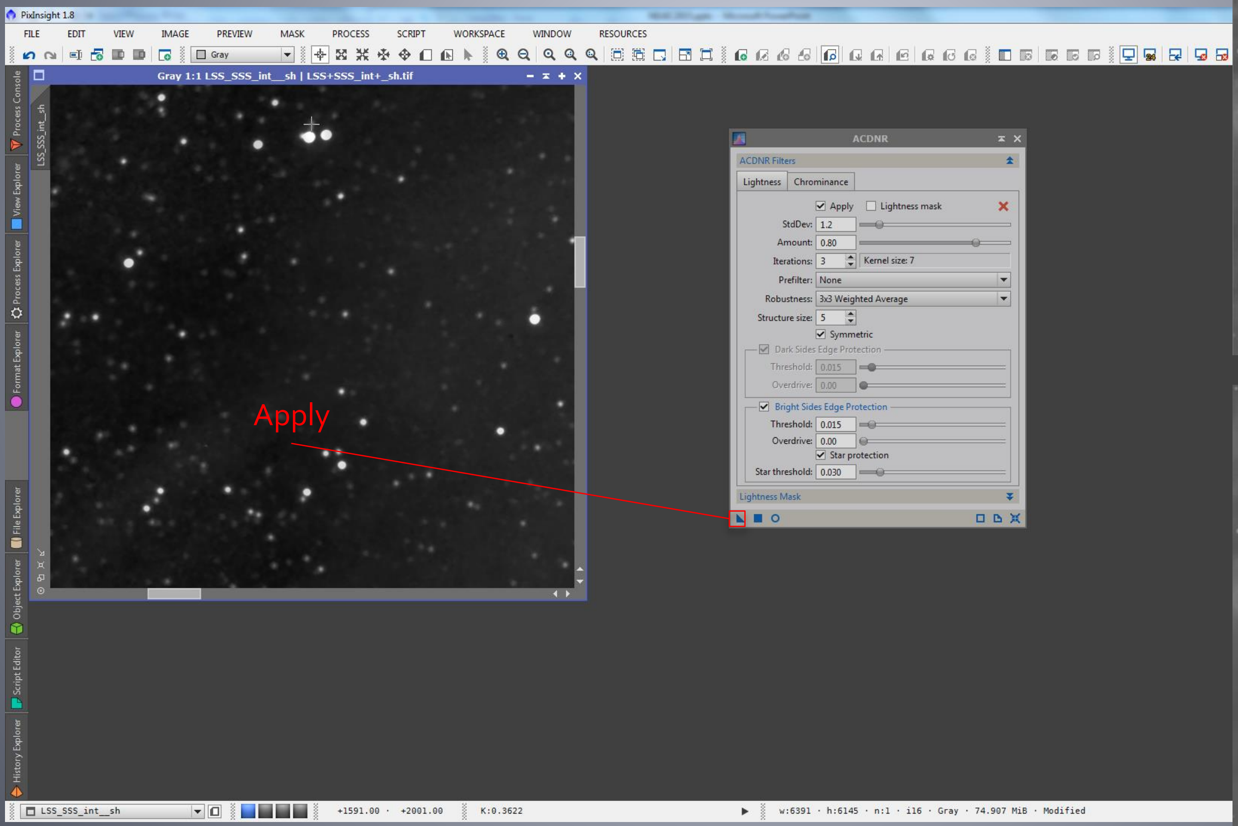
Adjust Amount
Value between 0.1 and 1

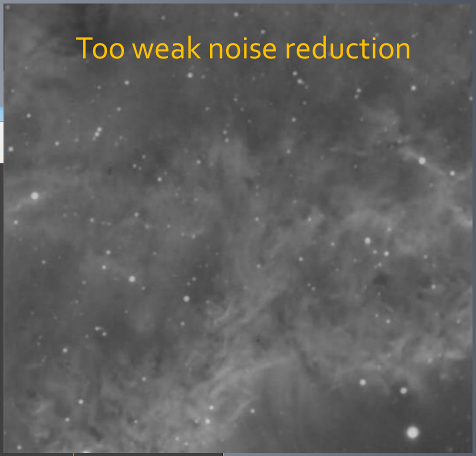
Adjust Number of Iterations.
To get a good result you must reduce the Amount and increase the number of iteration

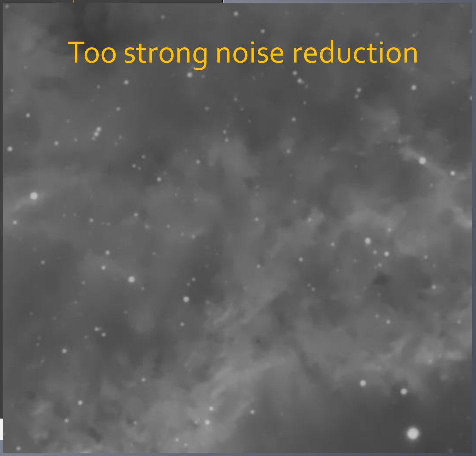
NOTE: To learn more about noise reduction and edge protection, go to http://www.deepskycolors.com/PixInsight/NoiseReduction.html

Composing advanced LRGB images in false colors
Bringing out the structural details
Reducing noise

- Apply ACDNR on the image







NOTE: If the noise reduction is too weak or too strong, you can undo and ajust parameters

- Save image to HOS_LSS+SSS_exp+_sh_acdnr.tif

Composing advanced LRGB images in false colors

Bringing out the structural details

Reducing star diameters to emphasize the nebula

BEFORE

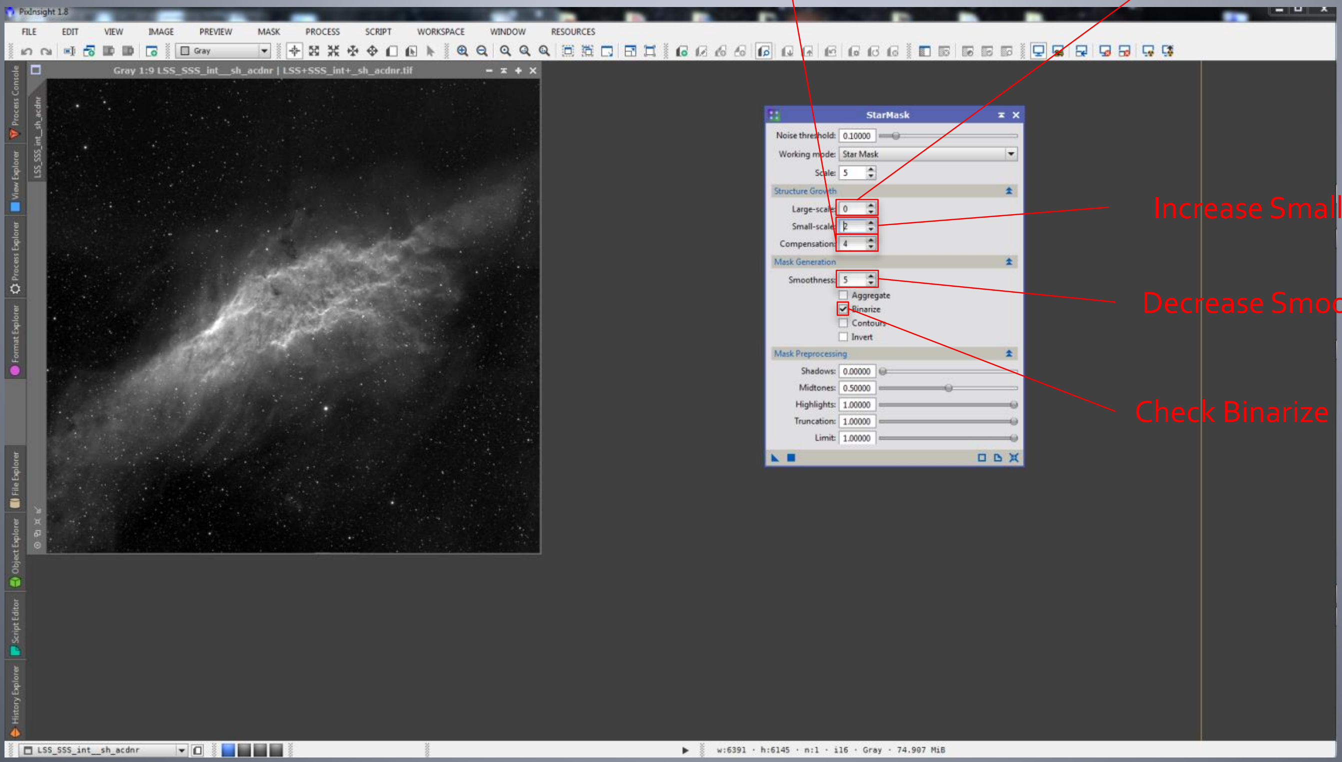
AFTER

Composing advanced LRGB images in false colors
Bringing out the structural details
Reducing star diameters to emphasize the nebula

- Open PixInsight
- Open file HOS_LSS+SSS_exp+_sh_acdnr.tif
- Open StarMask

Set Large-Scale to zero

Increase Compensation to 4 or more



Increase Small-Scale to 2 or more

Decrease Smoothness to 5 or less

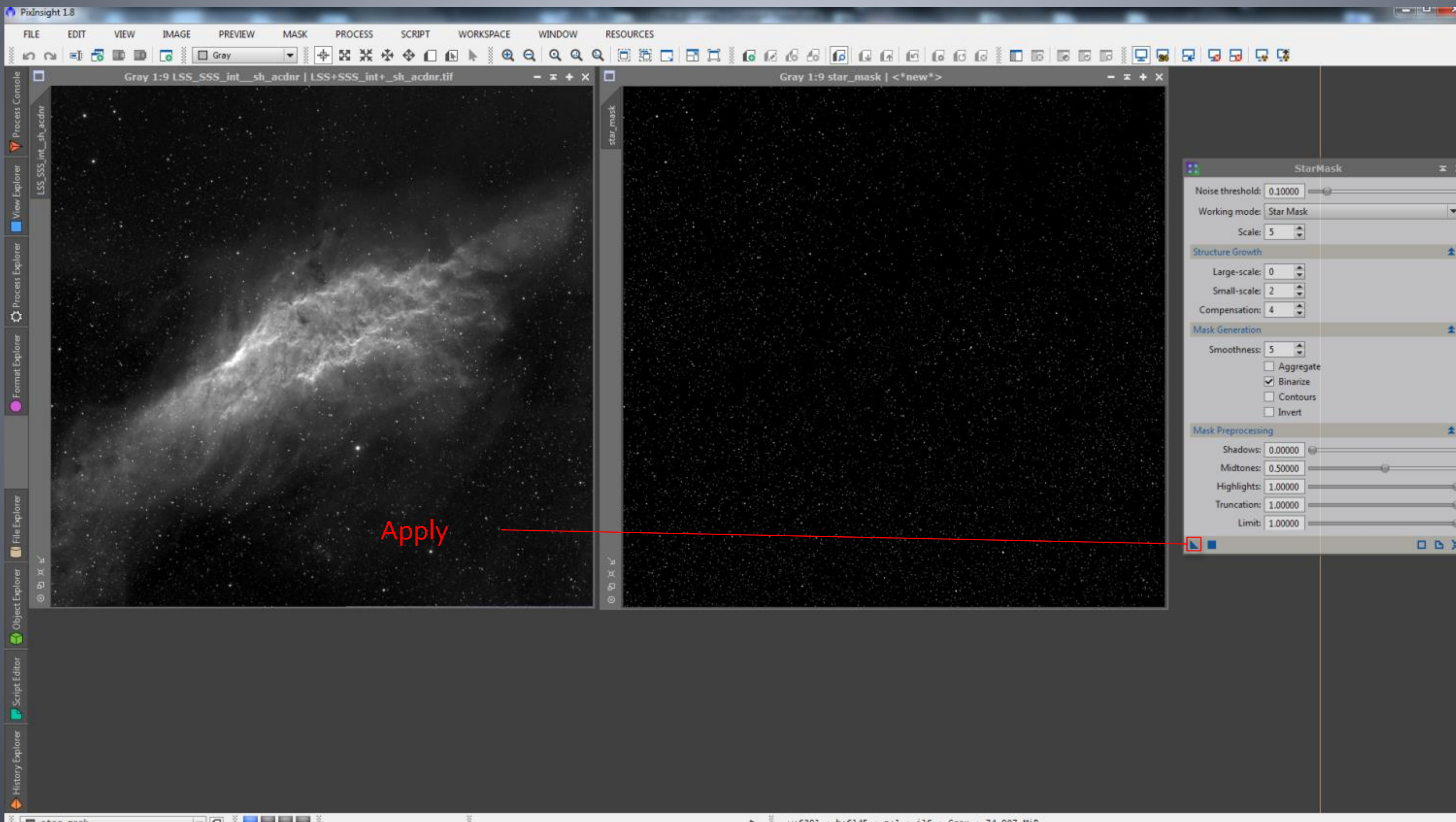
Check Binarize

Composing advanced LRGB images in false colors

Bringing out the structural details

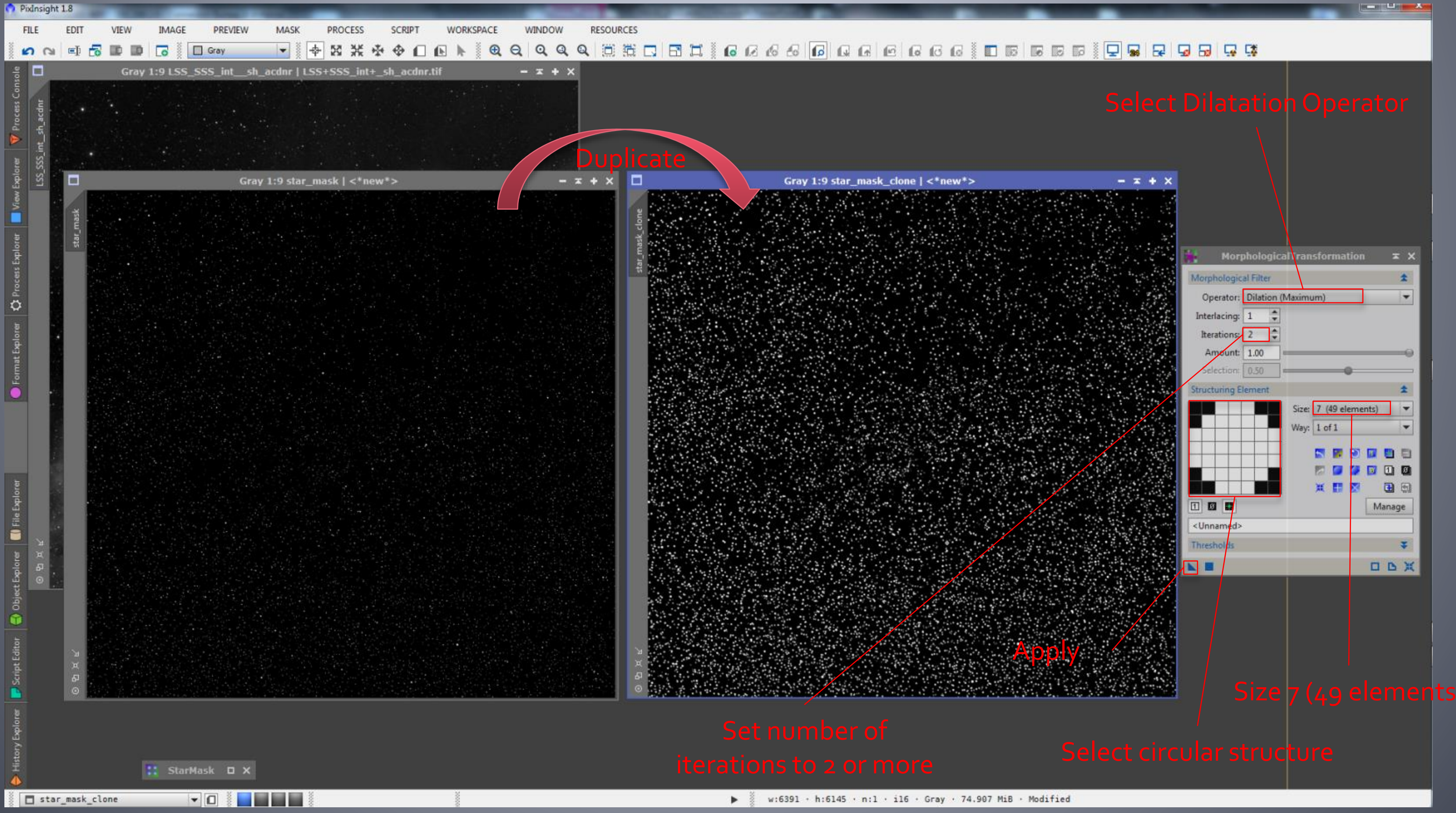
Reducing star diameters to emphasize the nebula

- Apply StarMask



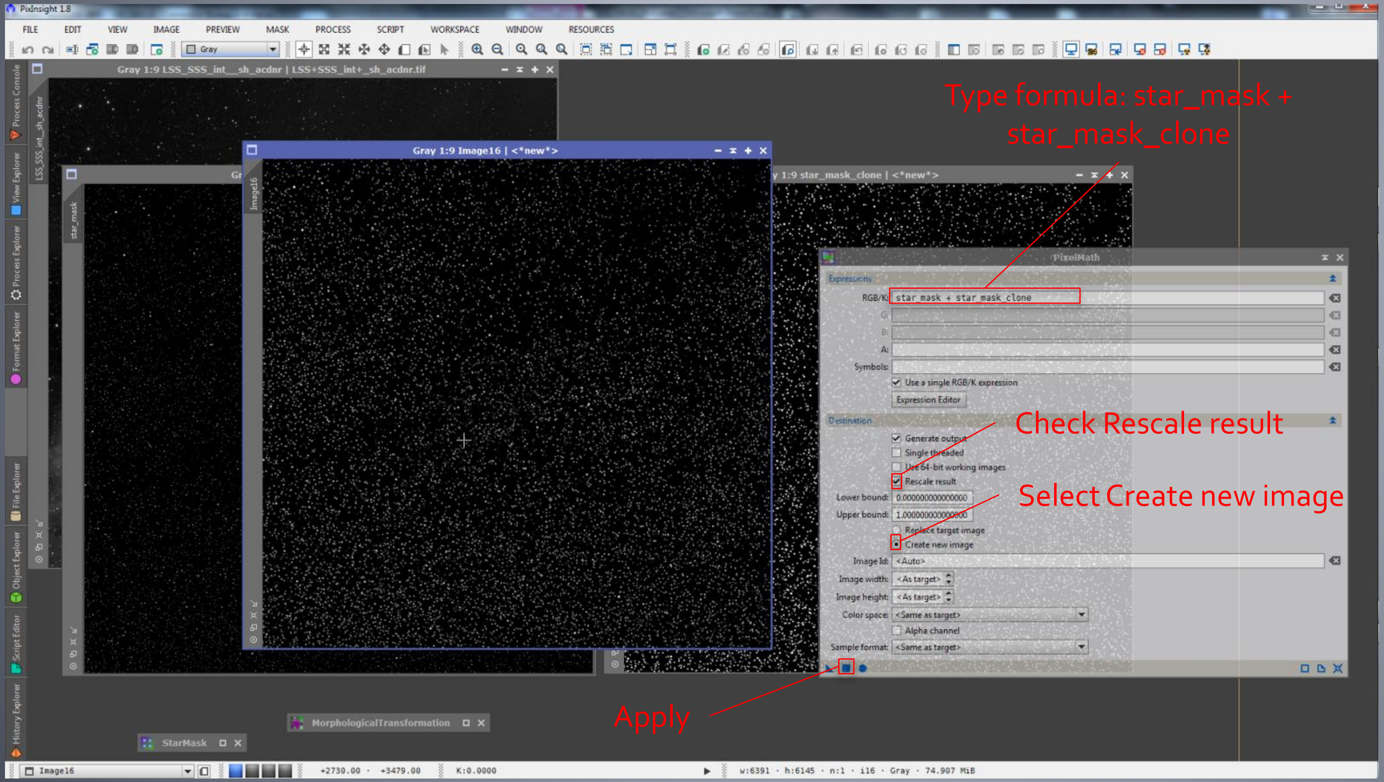
Composing advanced LRGB images in false colors
Bringing out the structural details
Reducing star diameters to emphasize the nebula

- Duplicate StarMask
- Open MorphologicalTransformation



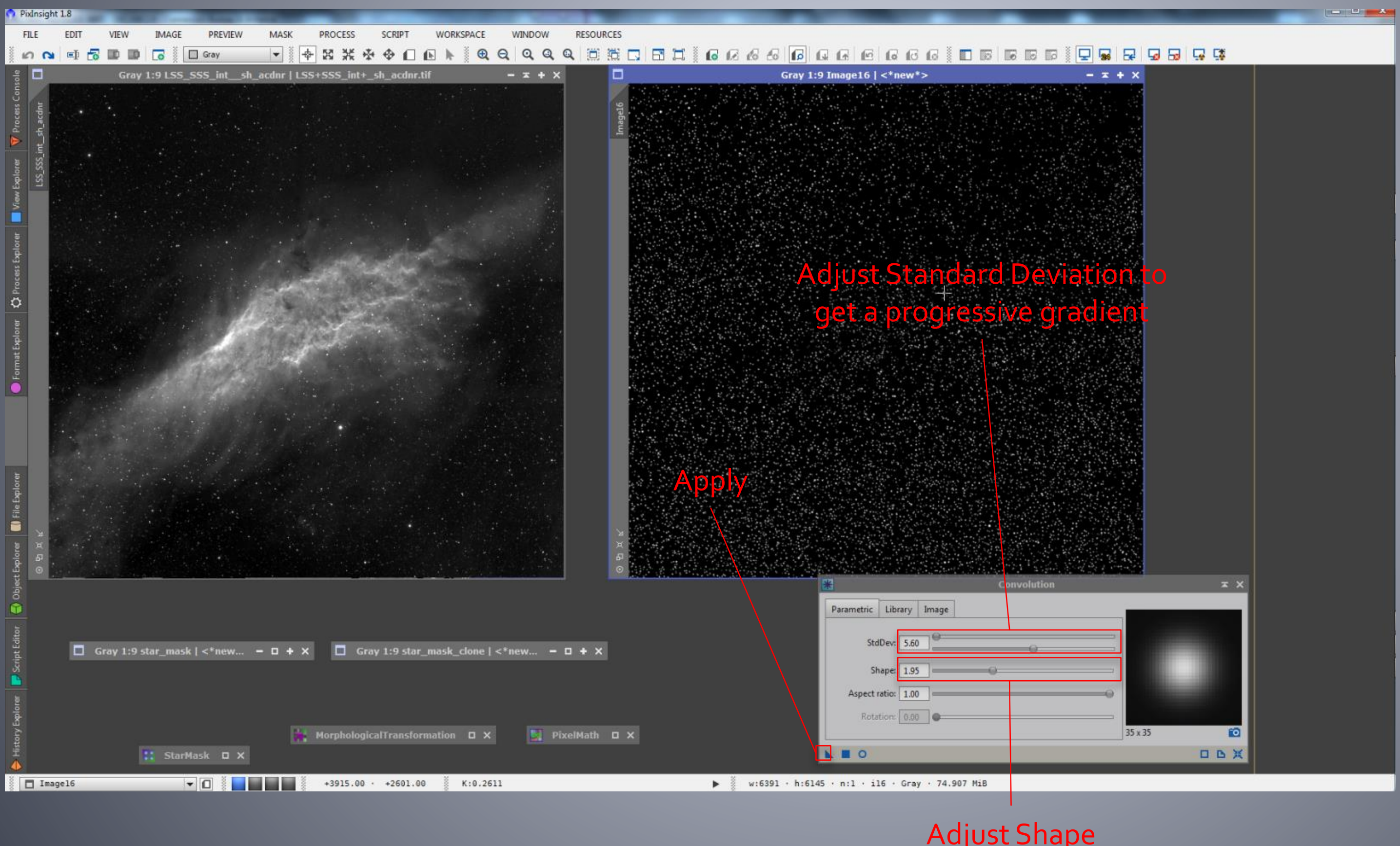
Composing advanced LRGB images in false colors
Bringing out the structural details
Reducing star diameters to emphasize the nebula

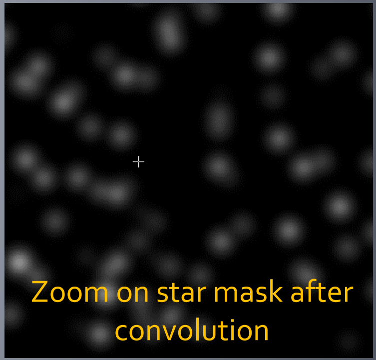
- Open PixelMath



Composing advanced LRGB images in false colors
Bringing out the structural details
Reducing star diameters to emphasize the nebula

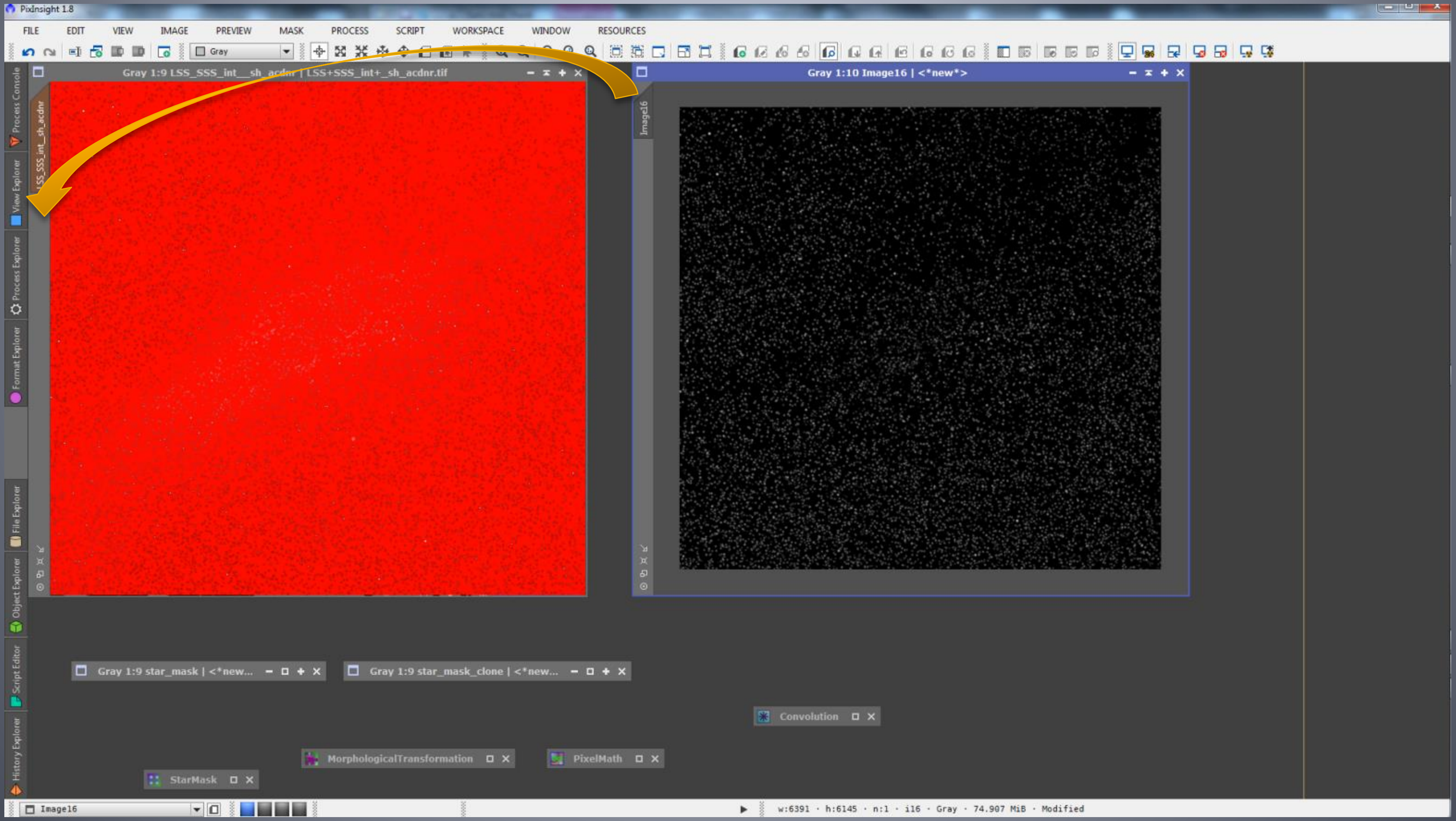
- Open Convolution





Composing advanced LRGB images in false colors
Bringing out the structural details
Reducing star diameters to emphasize the nebula

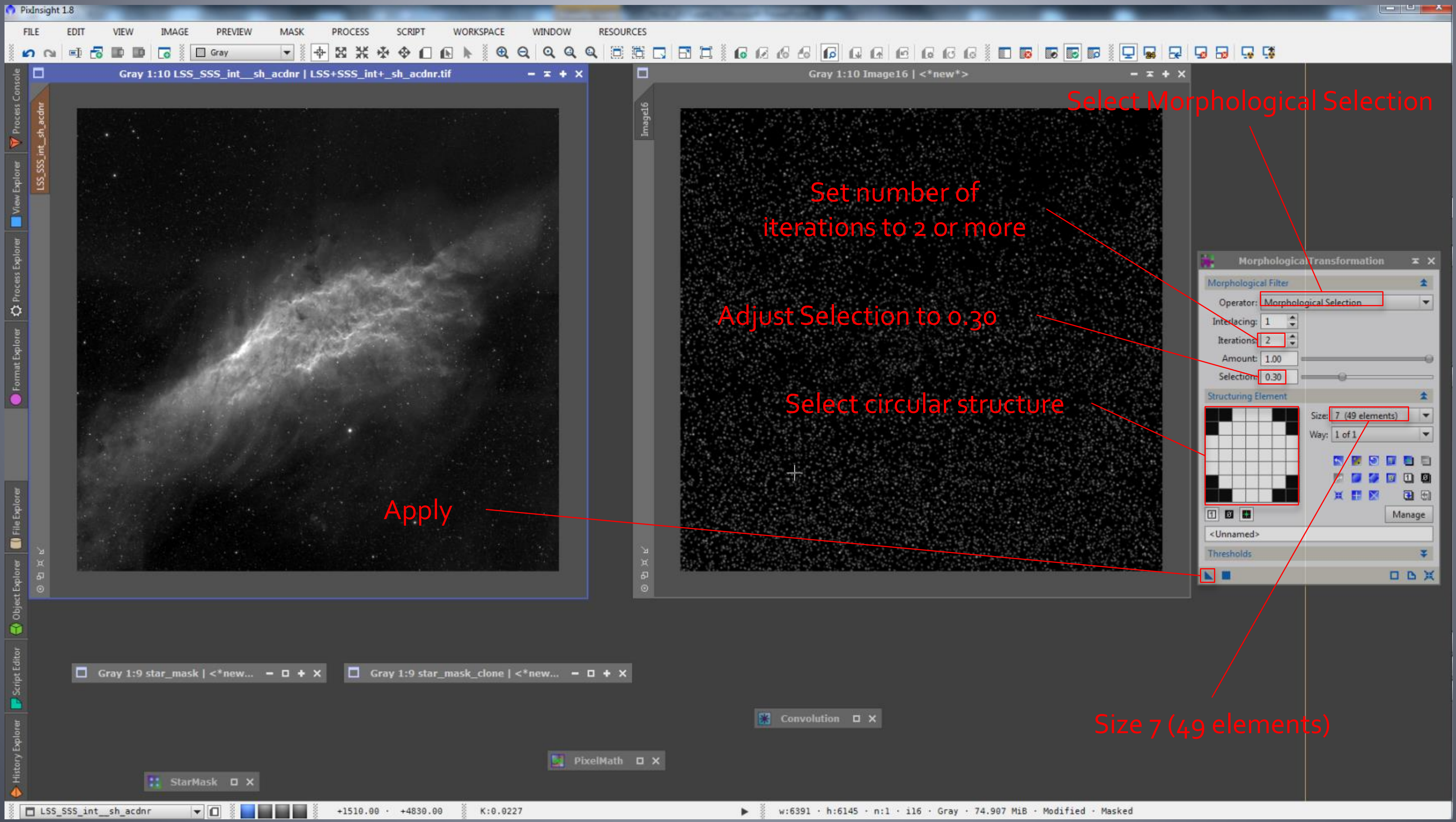
- Drag & Drop star mask to the image



NOTE: To be able to see the image behind the mask you must hide the mask

Composing advanced LRGB images in false colors
Bringing out the structural details
Reducing star diameters to emphasize the nebula

- Open MorphologicalTransformation



- Save image to HOS_LSS+SSS_exp+_sh_acdnr_star-.tif

Composing advanced LRGB images in false colors

Bringing out the structural details

Using mask with shadows and highlights to detach the nebula from the background

BEFORE

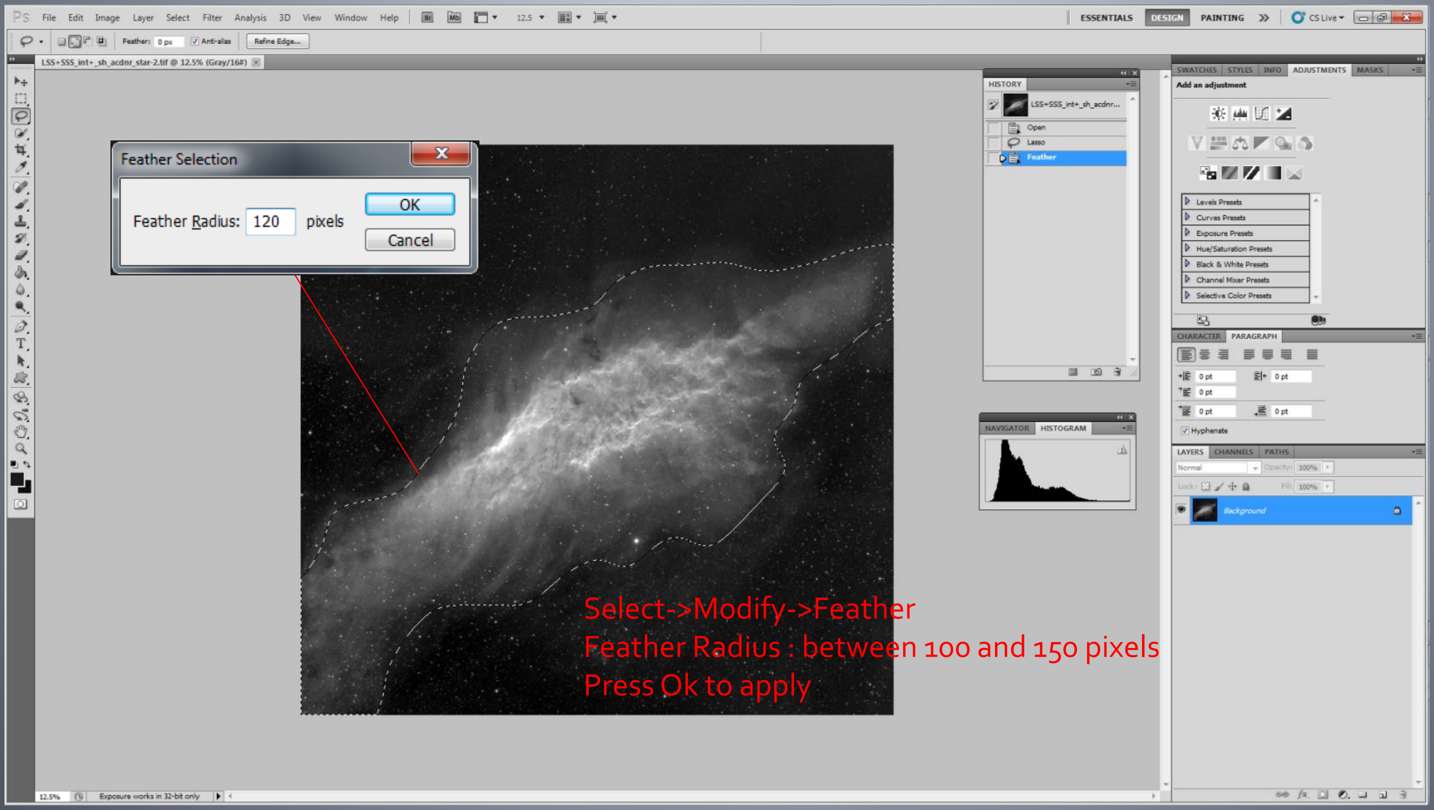
AFTER

Composing advanced LRGB images in false colors

Bringing out the structural details

Using mask with shadows and highlights to detach the nebula from the background

- Open PhotoShop
- Open file HOS_LSS+SSS_exp+_sh_acdnr_star-.tif
- Select the nebula with the lasso tool

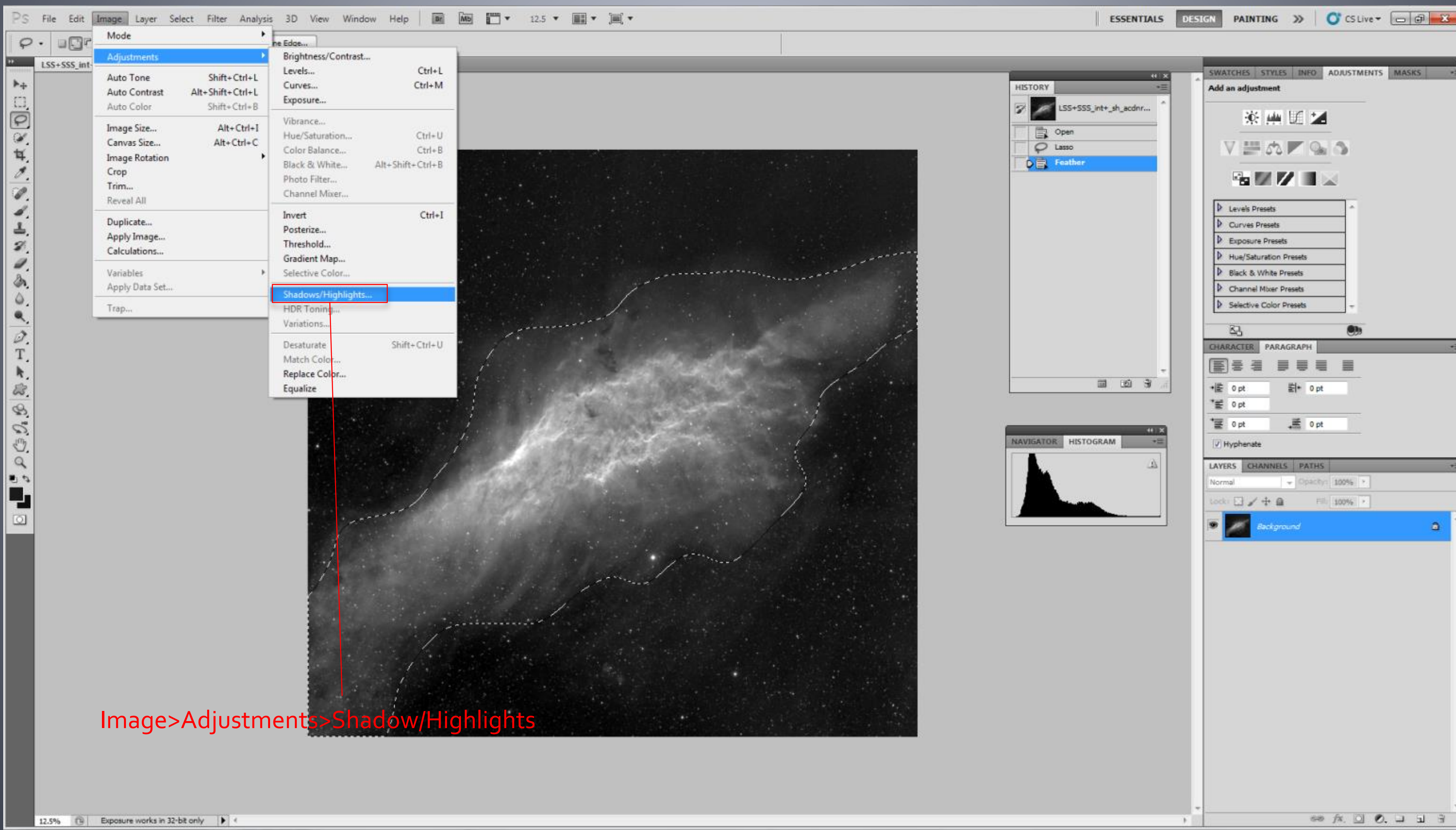


Composing advanced LRGB images in false colors

Bringing out the structural details

Using mask with shadows and highlights to detach the nebula from the background

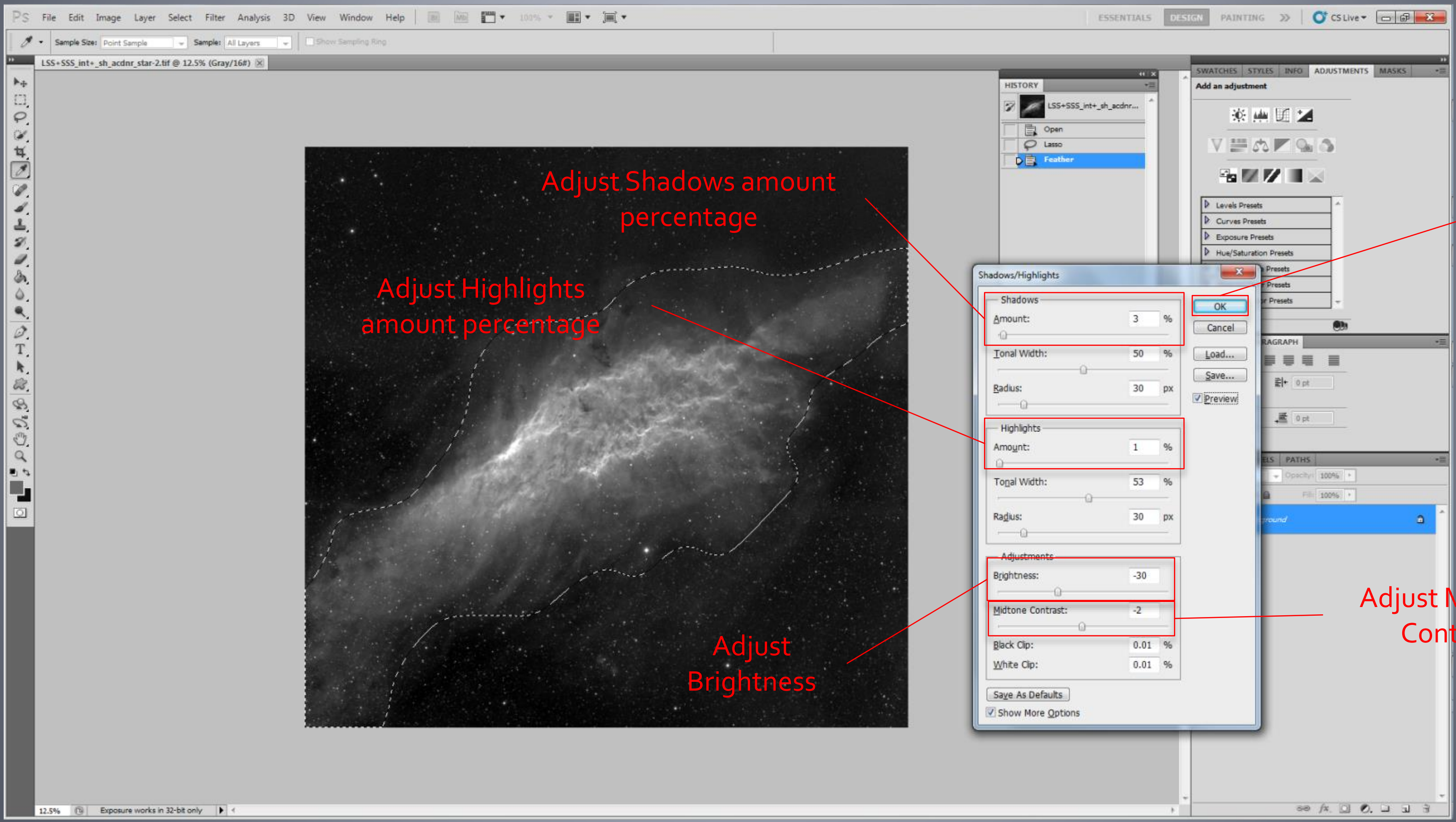
CEDIC



Composing advanced LRGB images in false colors

Bringing out the structural details

Using mask with shadows and highlights to detach the nebula from the background

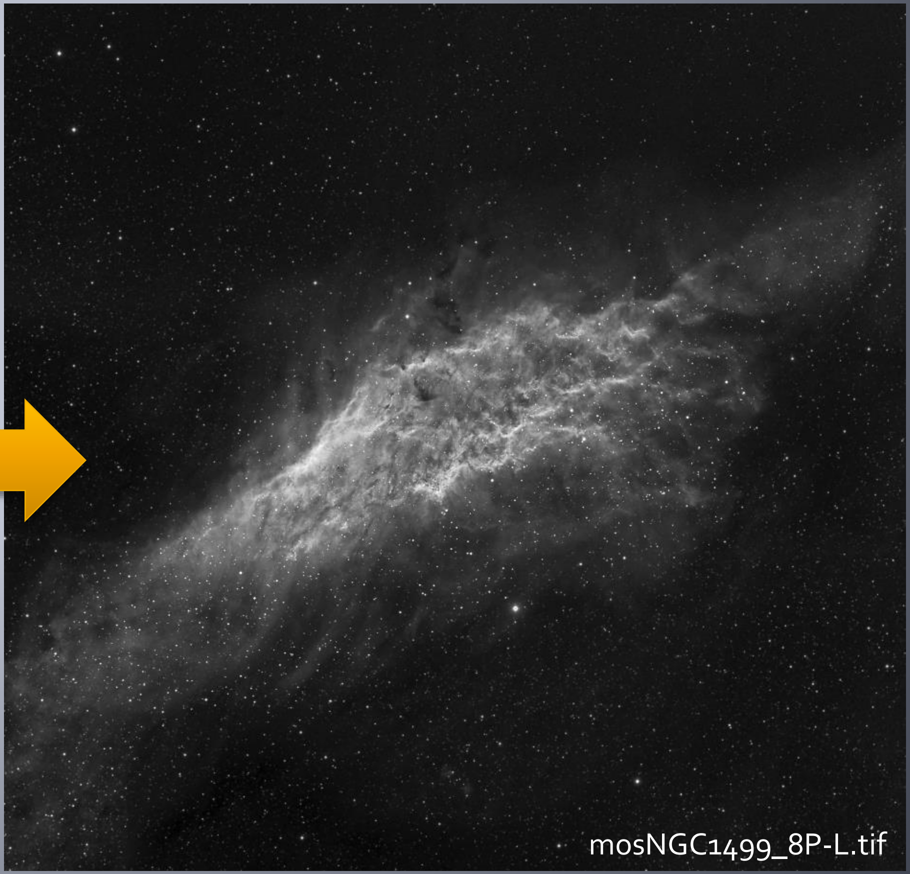


- Save image to HOS_LSS+SSS_exp+_sh_acdnr_star-_msh.tif

NOTE: The shadows and highlights process is effective only in the selected area

Composing advanced LRGB images in false colors
Bringing out the structural details
Using mask with smart sharpen to sharpen structural details

BEFORE

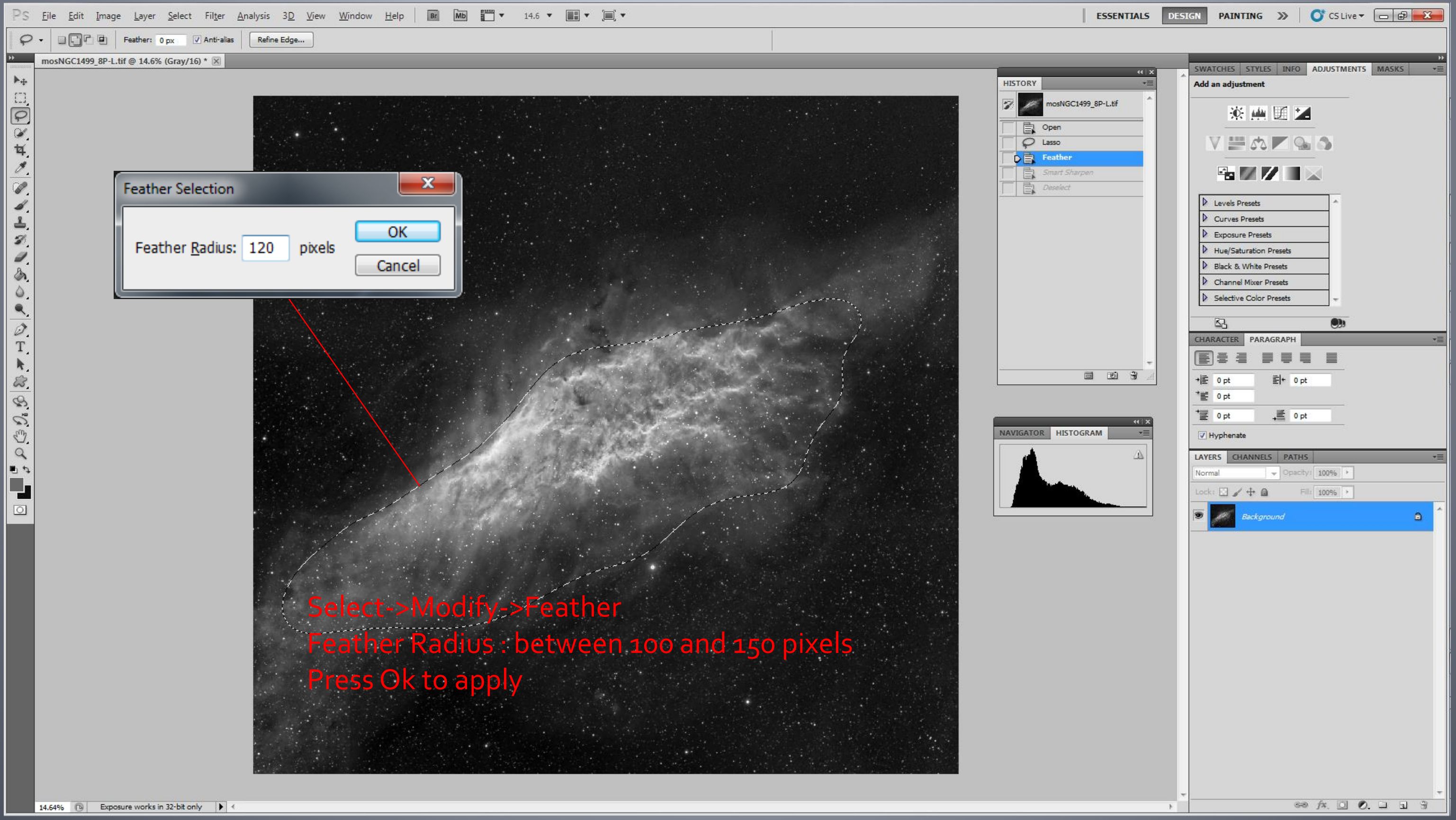


AFTER

Composing advanced LRGB images in false colors
Bringing out the structural details
Using mask with smart sharpen to sharpen structural details

CEDIC

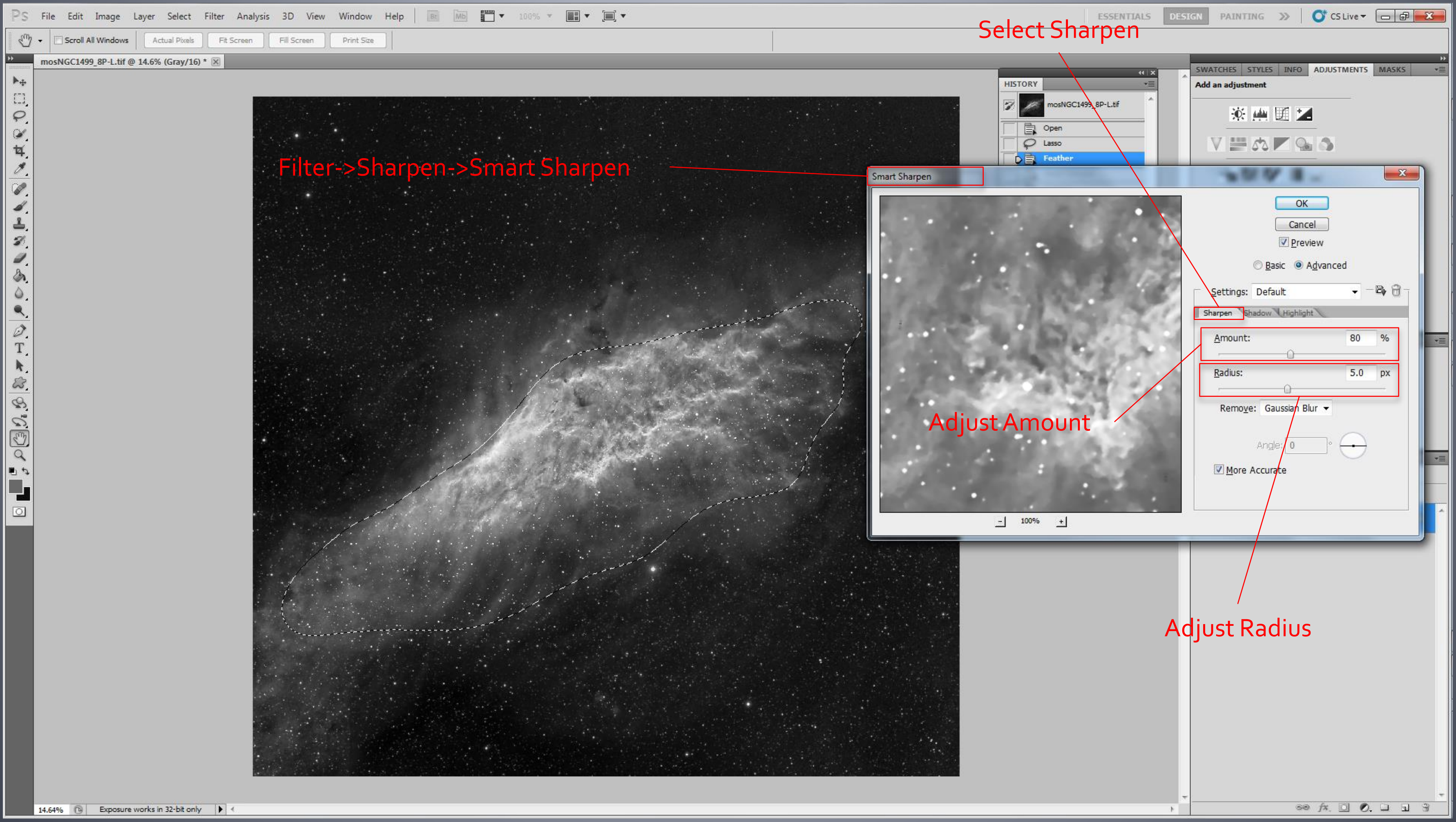
- Open PhotoShop
- Open file HOS_LSS+SSS_exp+_sh_acdnr_star-_msh.tif
- Select the nebula with the lasso tool



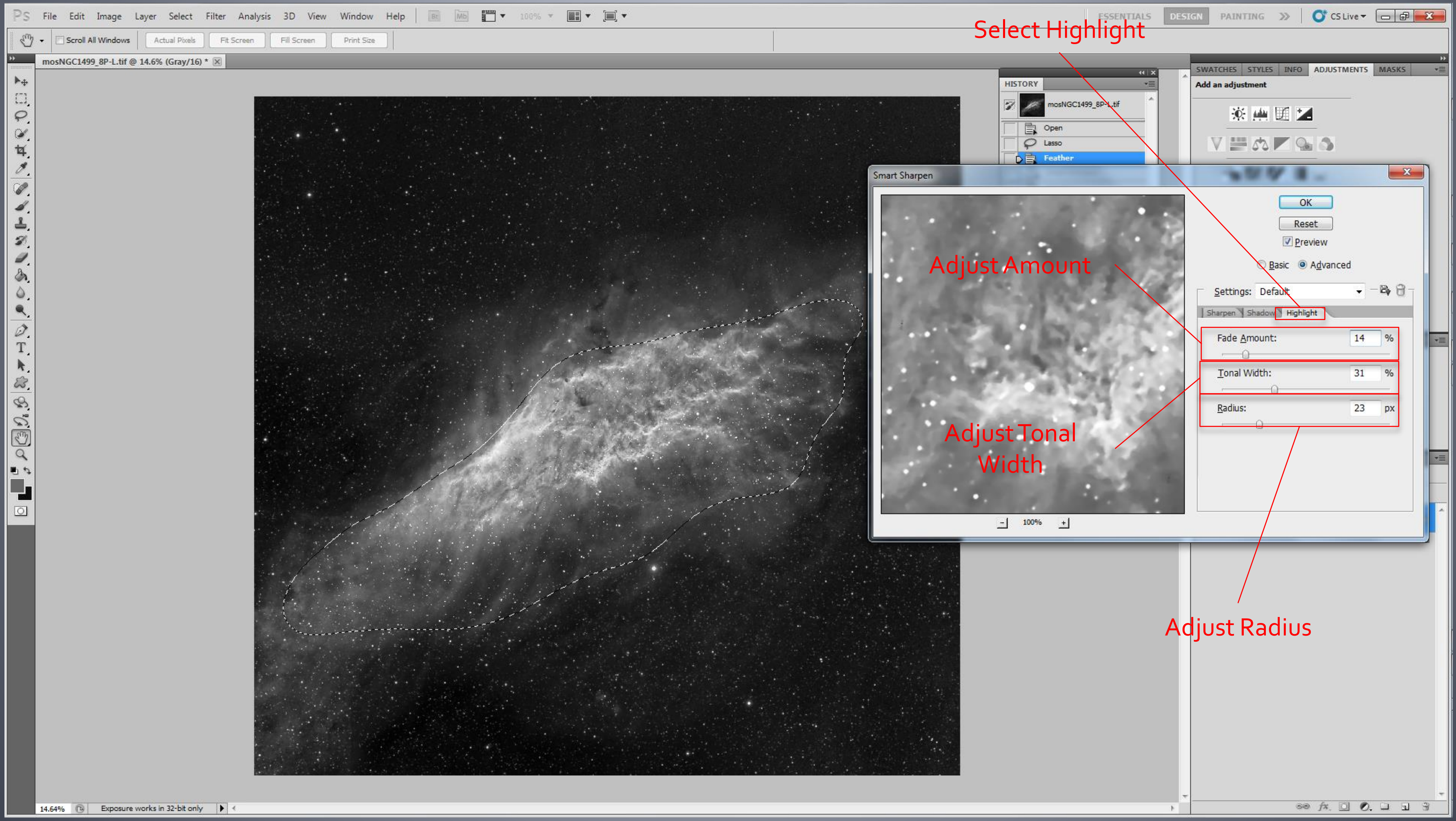
Composing advanced LRGB images in false colors

Bringing out the structural details

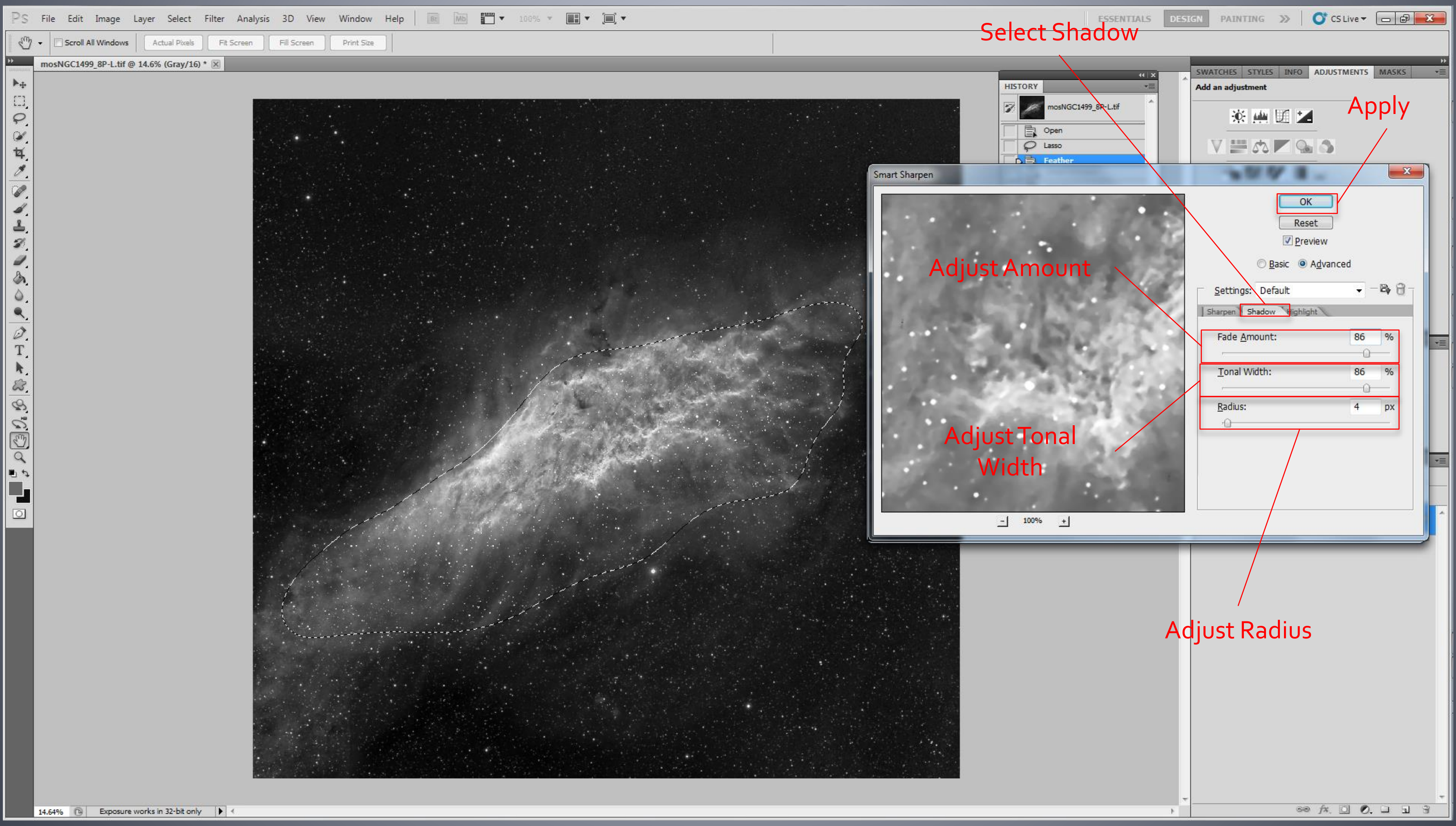
Using mask with smart sharpen to sharpen structural details



Composing advanced LRGB images in false colors
Bringing out the structural details
Using mask with smart sharpen to sharpen structural details



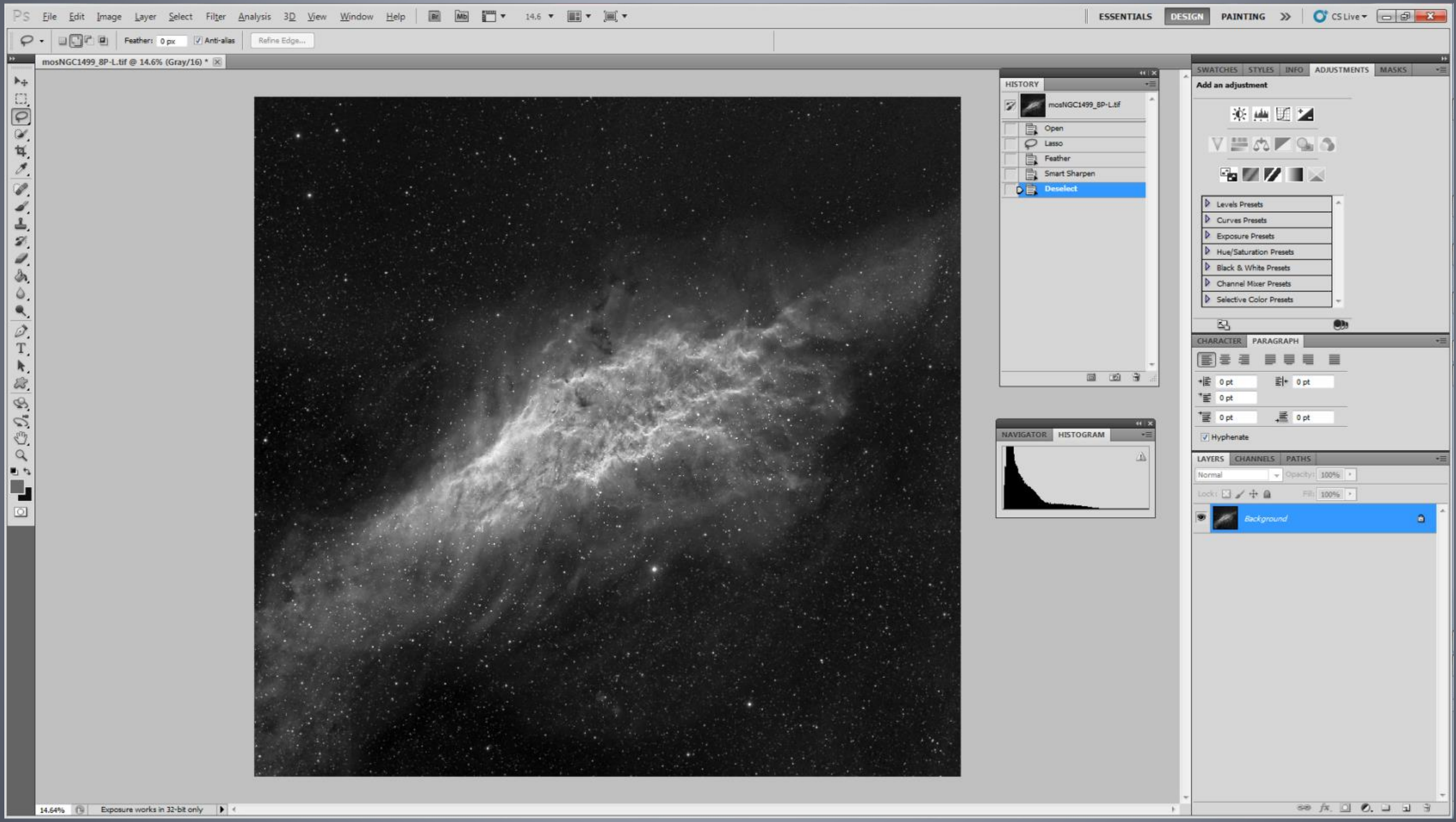
Composing advanced LRGB images in false colors
Bringing out the structural details
Using mask with smart sharpen to sharpen structural details



Composing advanced LRGB images in false colors

Bringing out the structural details

Using mask with smart sharpen to sharpen structural details



- Save image to mosNGC1499_8P-L.tif

Composing advanced LRGB images in false colors
Bringing out the structural details

At this level the luminance is done.

Jellyfish nebula

Chapter 11: Creating chrominance master frame

Composing advanced LRGB images in false colors

Creating chrominance master frame

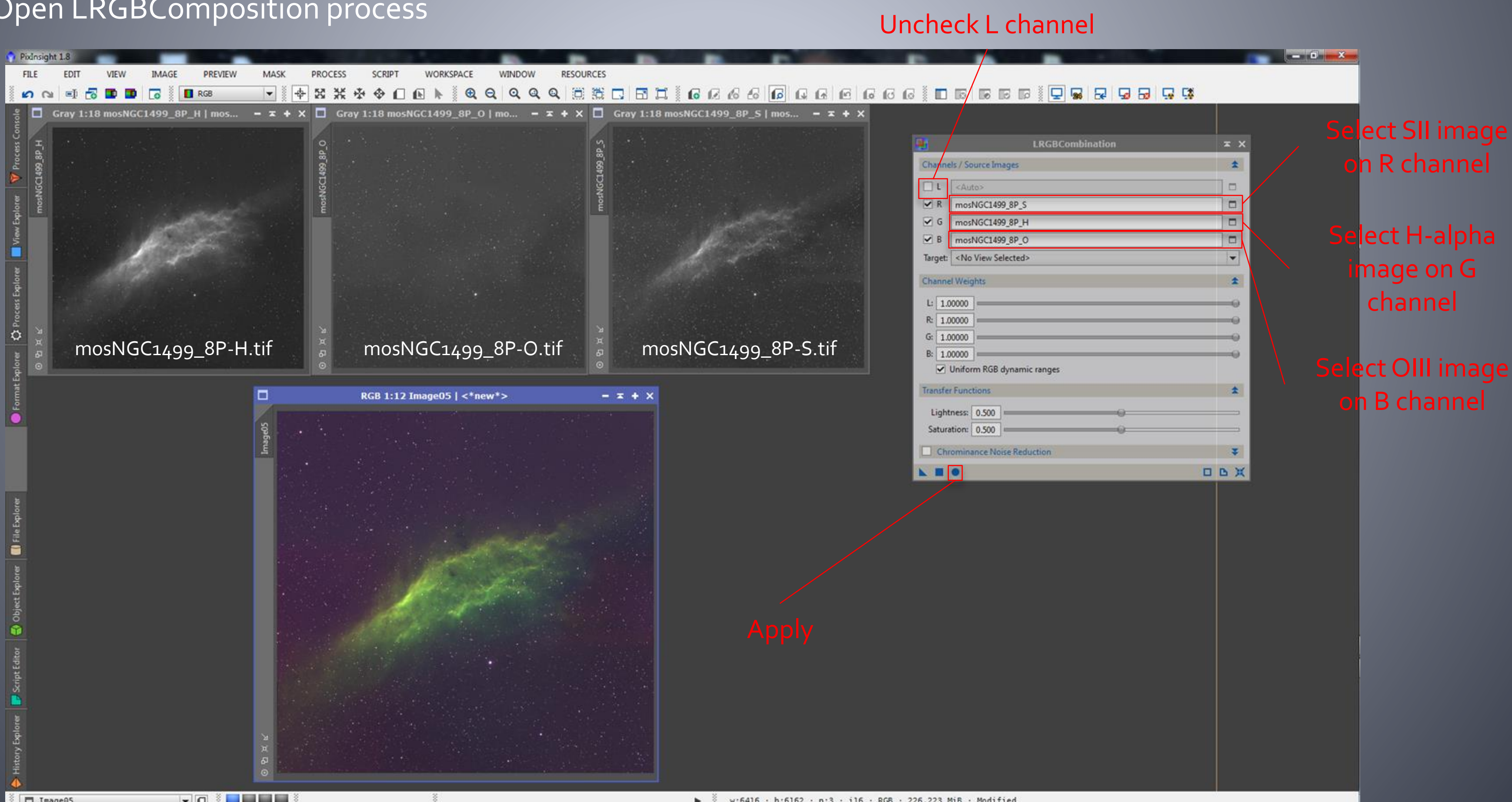
RAW data

LRGB composition

=

Composing advanced LRGB images in false colors
Creating chrominance master frame

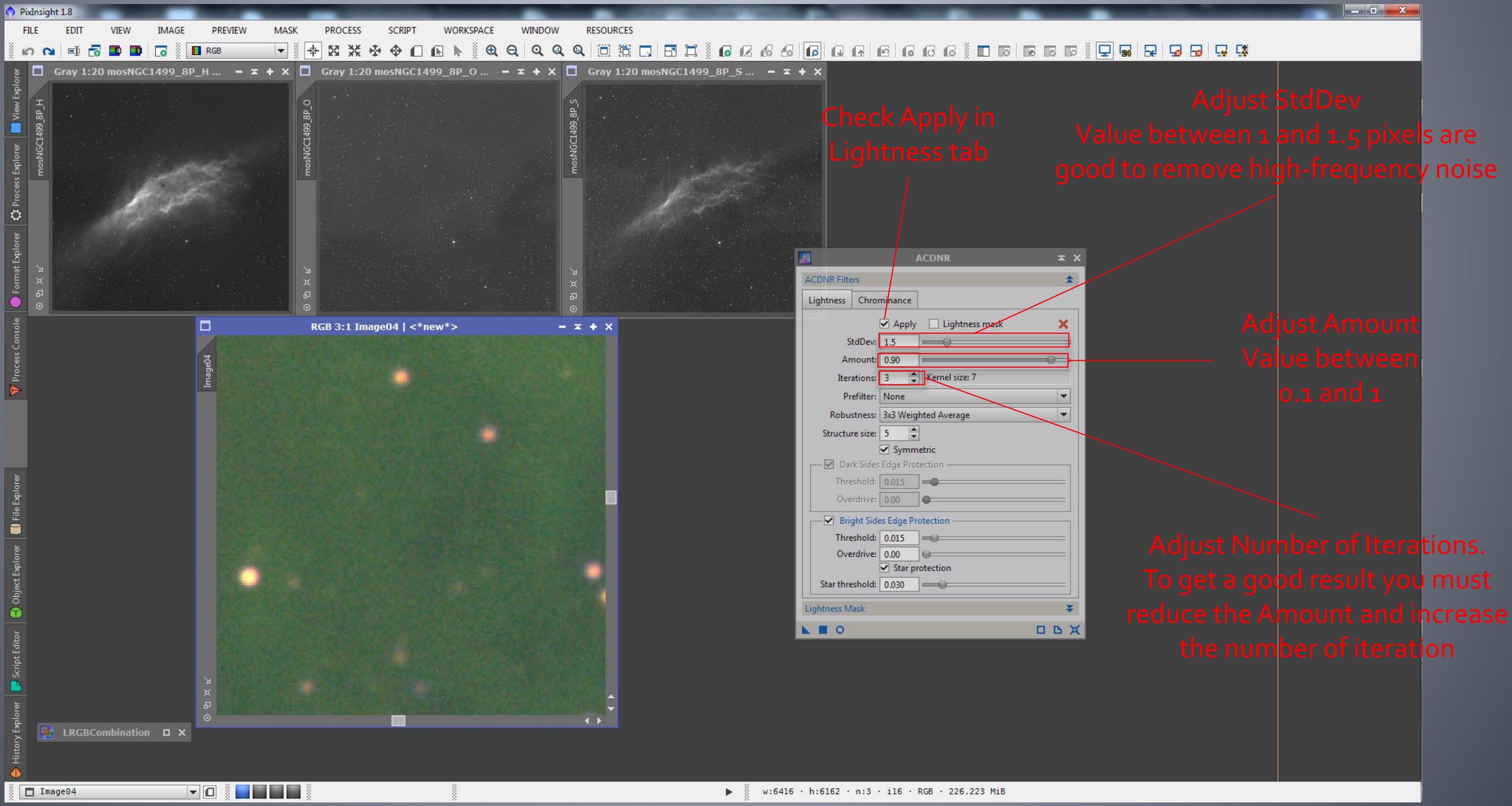
- Open PixInsight
- Open files mosNGC1499_8P_H.tif, mosNGC1499_8P_O.tif and mosNGC1499_8P_S.tif
- Open LRGBComposition process



Composing advanced LRGB images in false colors

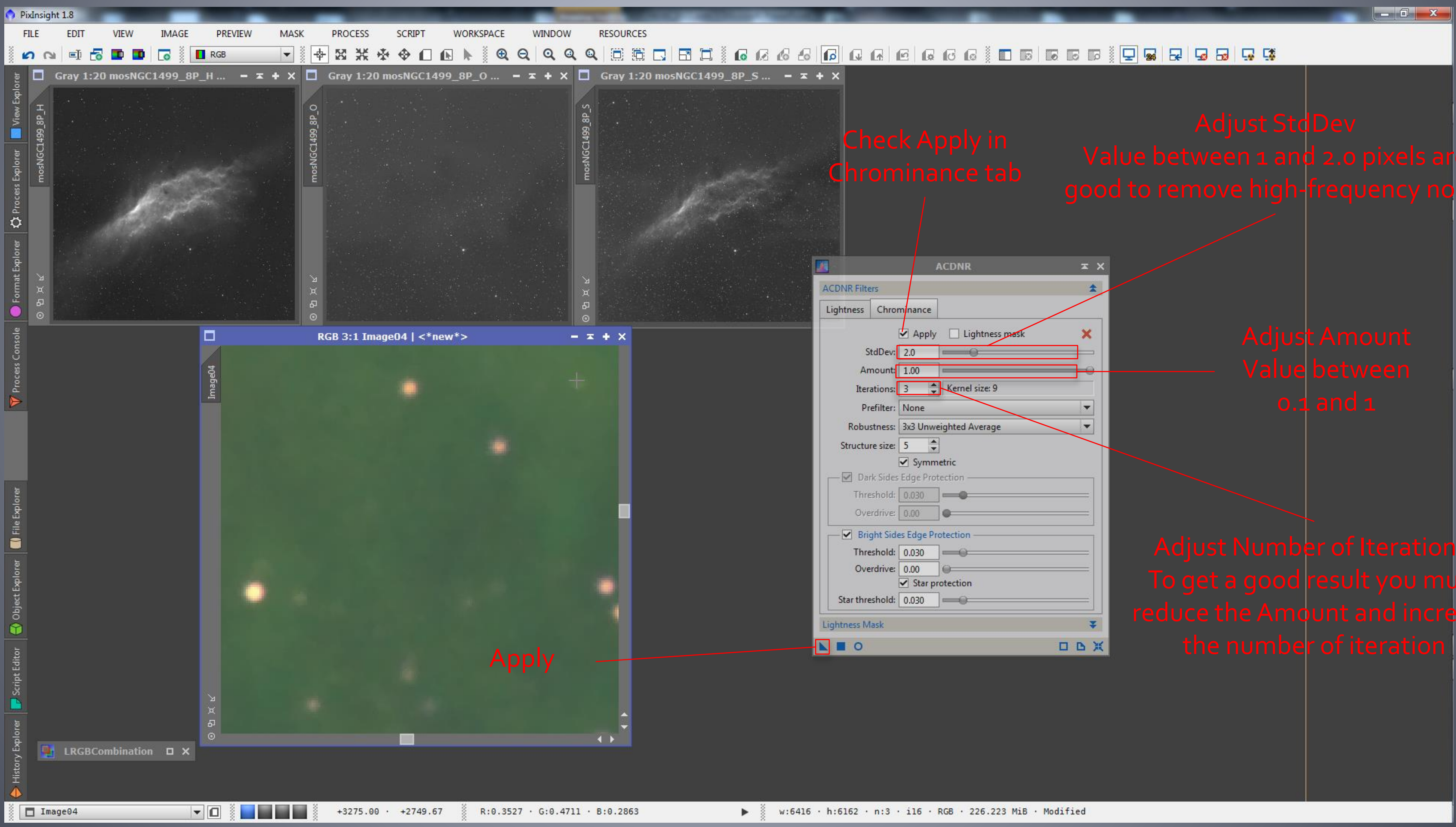
Creating chrominance master frame

- Open ACDNR process



Composing advanced LRGB images in false colors

Creating chrominance master frame

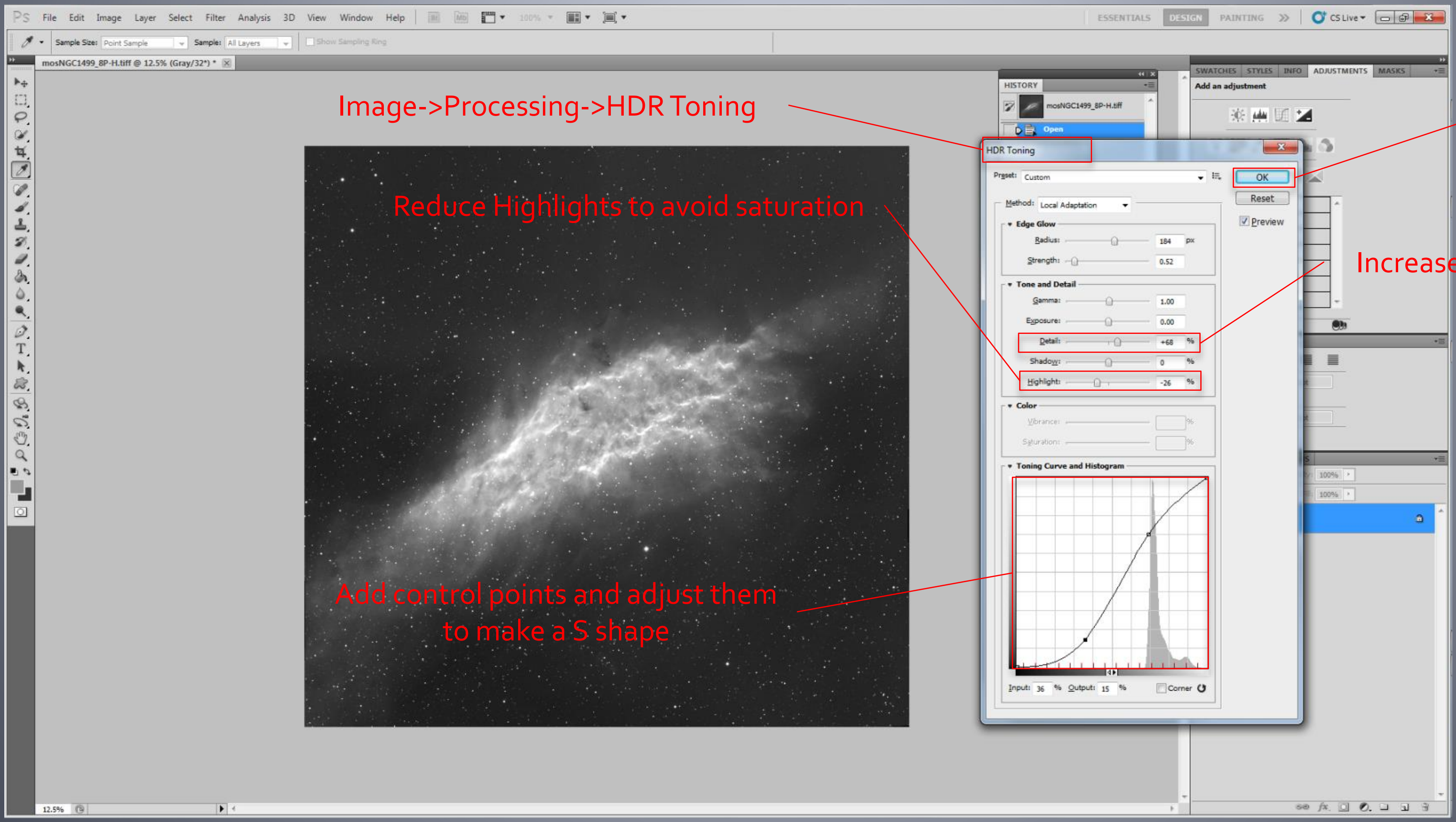


- Save the image as SHO_ColorMap.tif

Composing advanced LRGB images in false colors

Creating chrominance master frame

- Open Photoshop
- Open file mosNGC1499_8P_H.tif

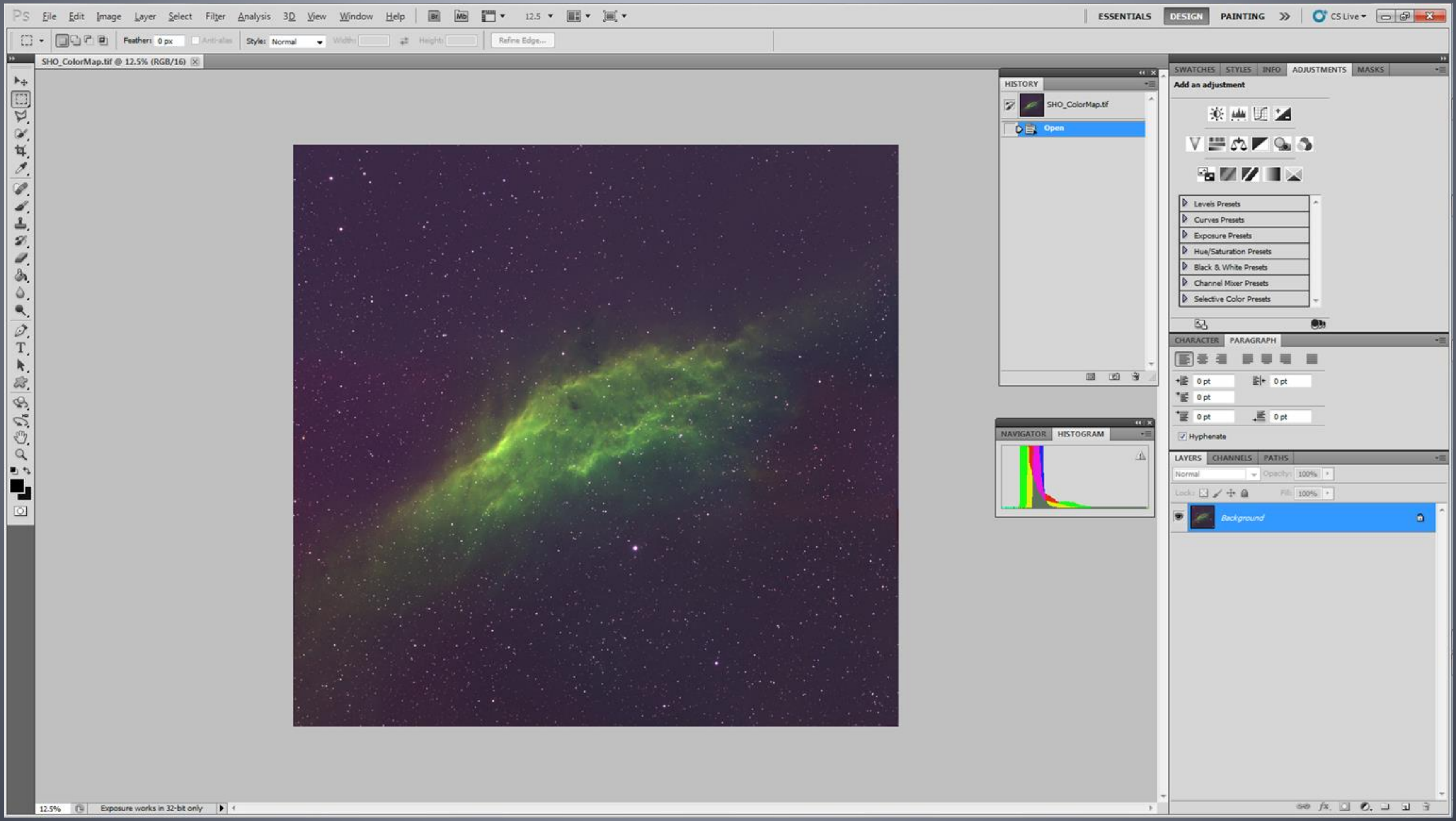


- Save image to mosNGC1499_8P_H_hdrto.tif

Composing advanced LRGB images in false colors

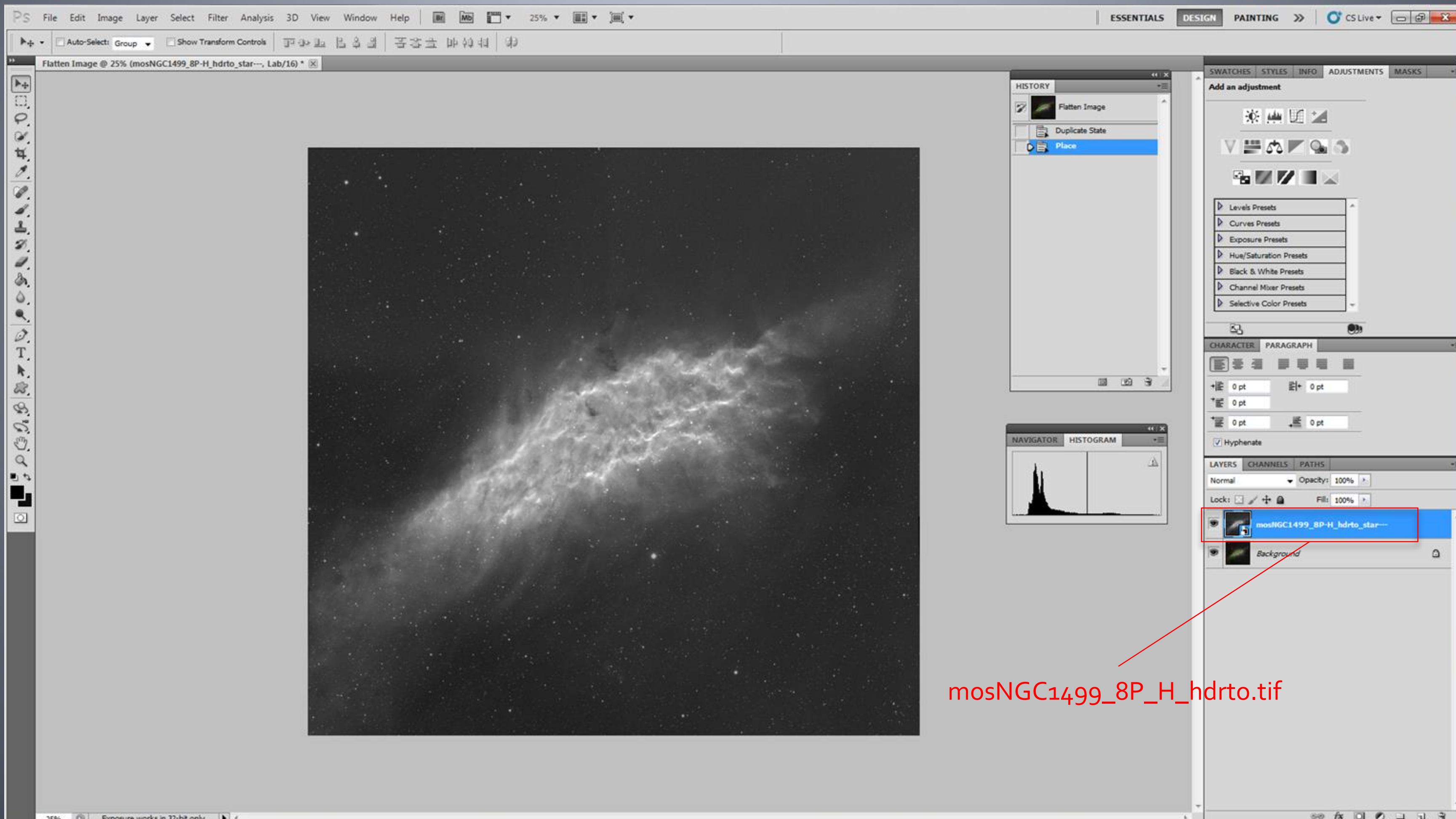
Creating chrominance master frame

- Open file SHO_ColorMap.tif



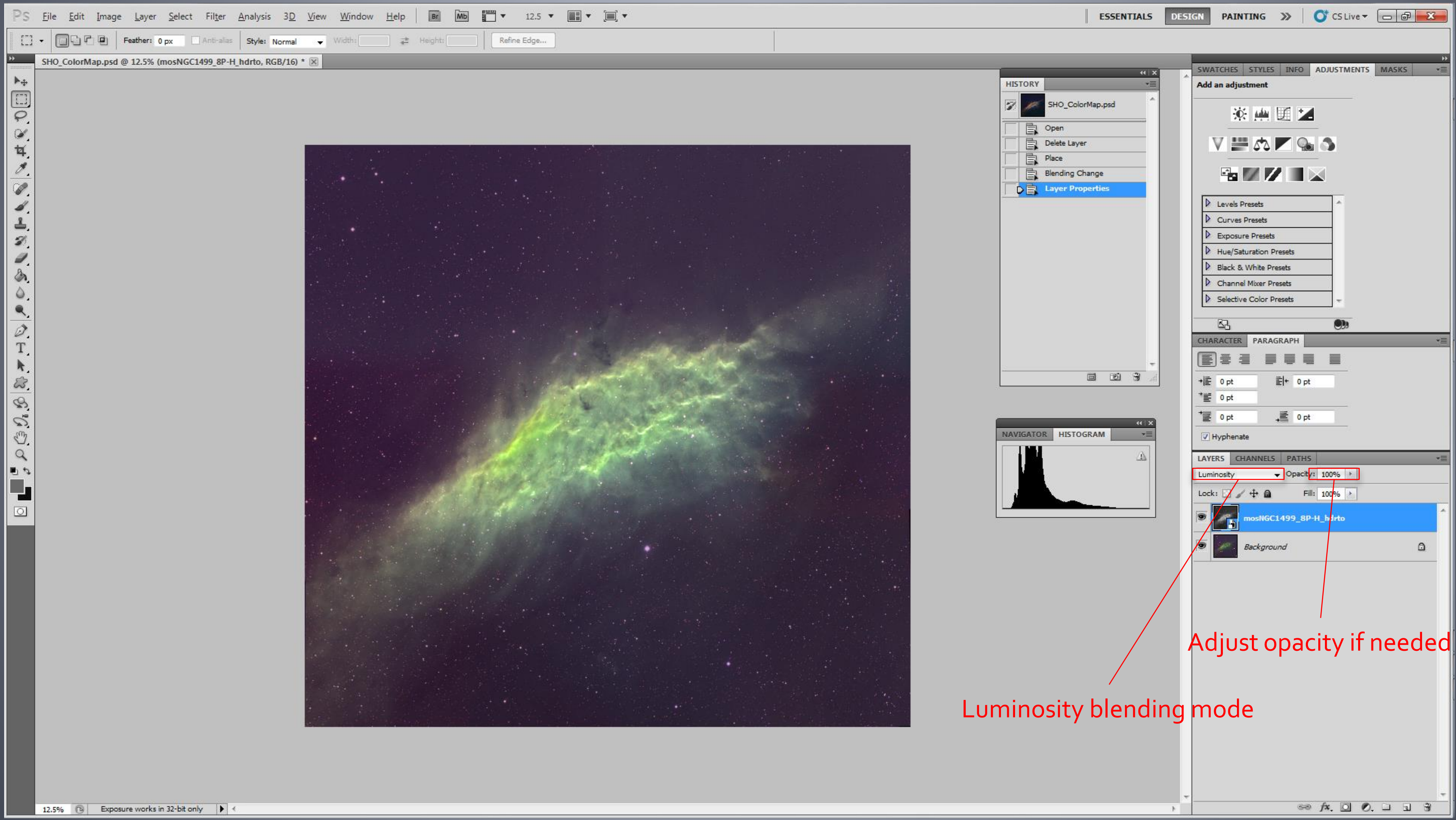
Composing advanced LRGB images in false colors
Creating chrominance master frame

- Place file mosNGC1499_8P_H_hdrto.tif on top of the SHO_ColorMap.tif



Composing advanced LRGB images in false colors

Creating chrominance master frame

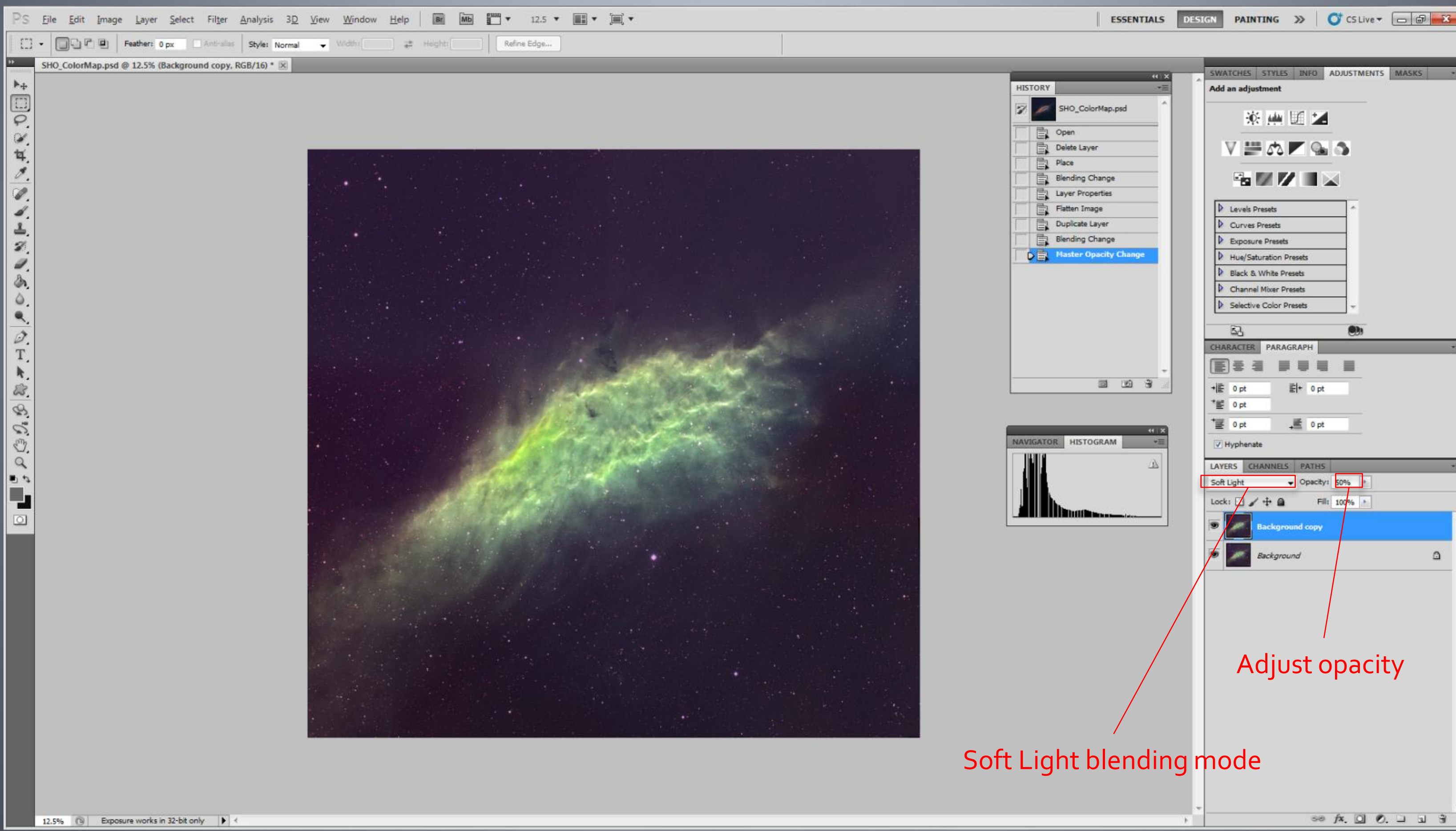


- Flatten the image

Composing advanced LRGB images in false colors

Creating chrominance master frame

- Duplicate background layer

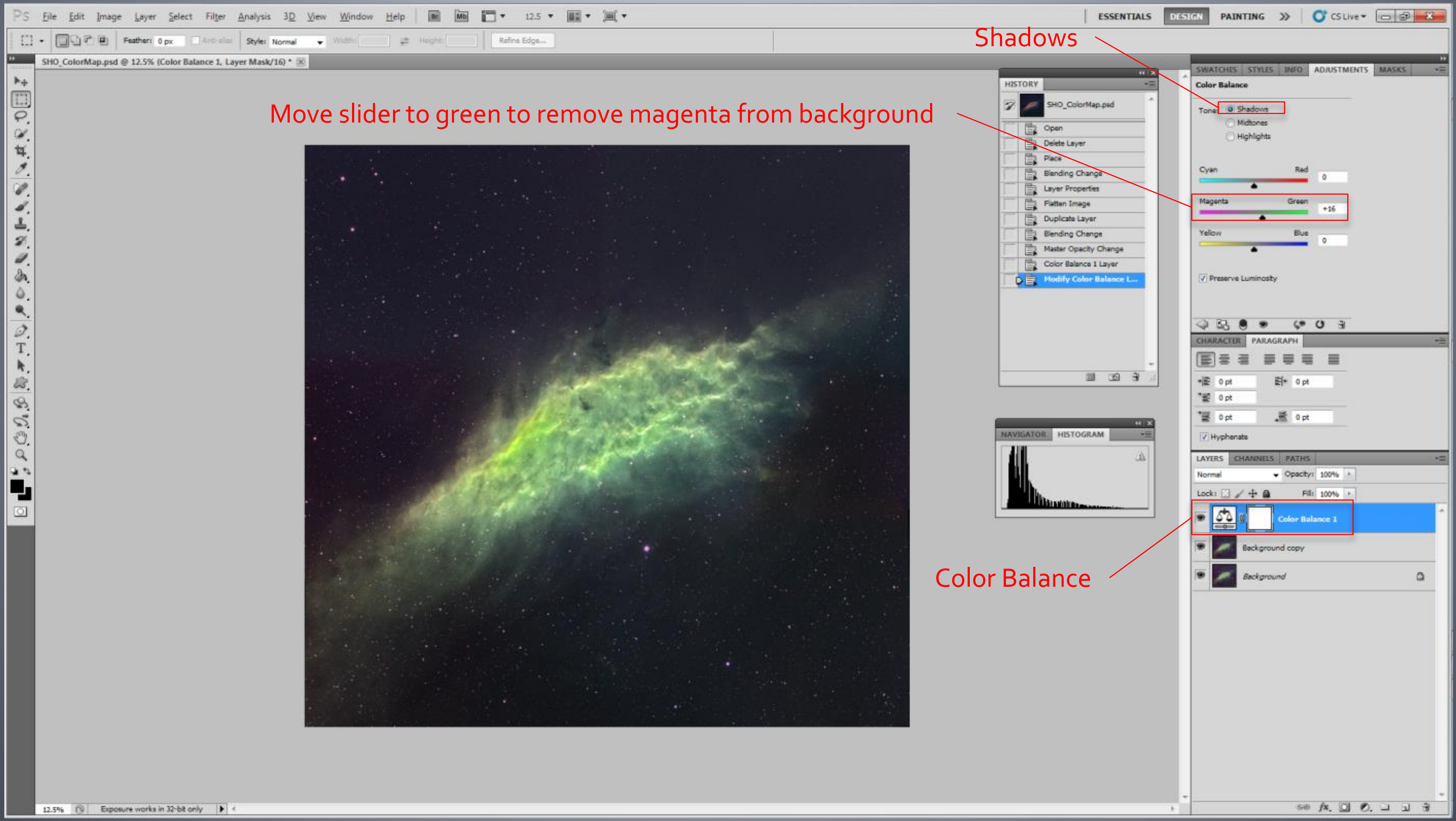


Areas where the blend color is lighter than 50% gray are lightened
Areas where the blend color is darker than 50% gray are darkened

Composing advanced LRGB images in false colors

Creating chrominance master frame

- Add Color Balance adjustment layer



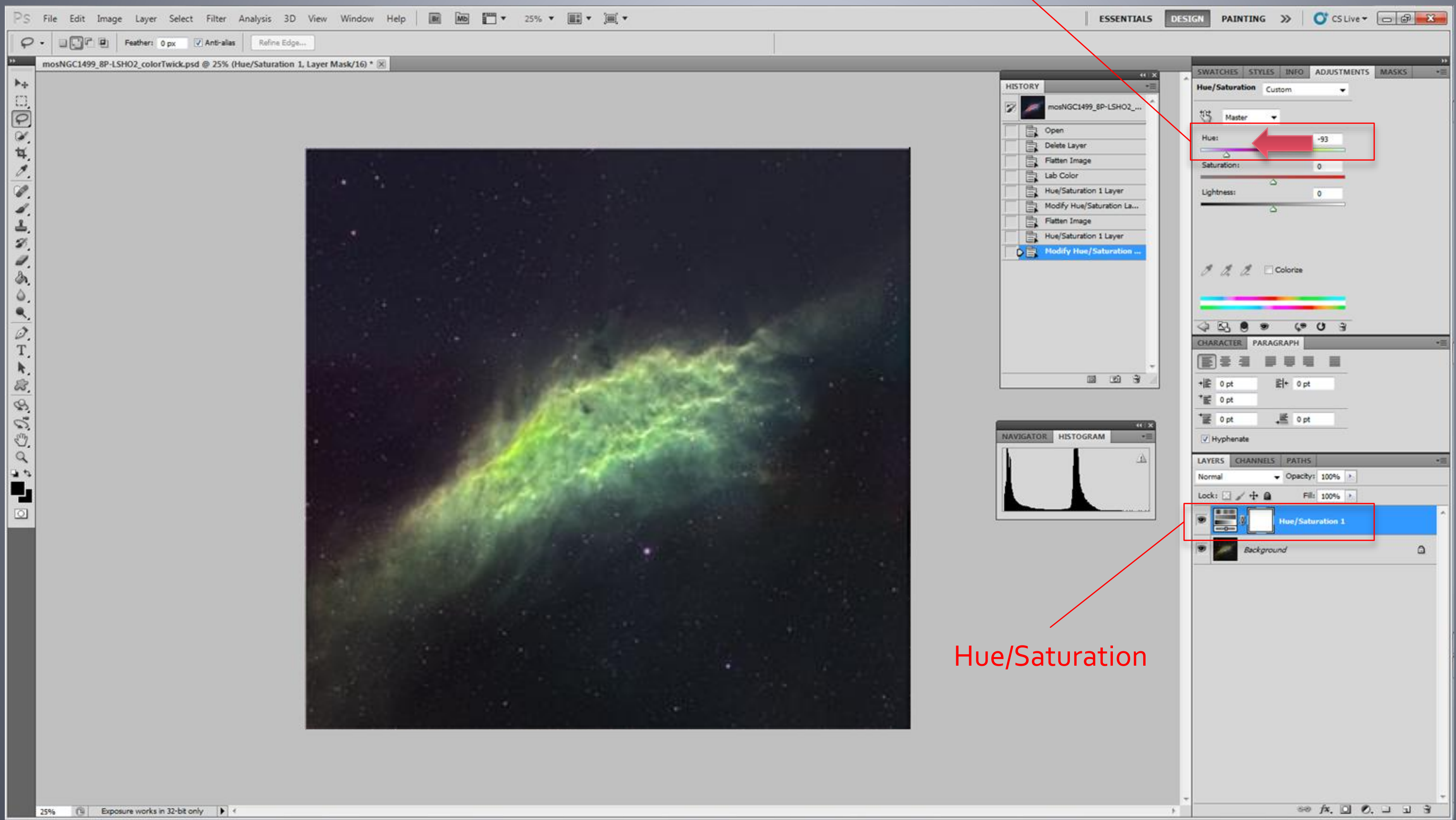
- Flatten the image

Composing advanced LRGB images in false colors

Creating chrominance master frame

- Select Image->Mode->Lab Color
- Add Hue/Saturation adjustment layer

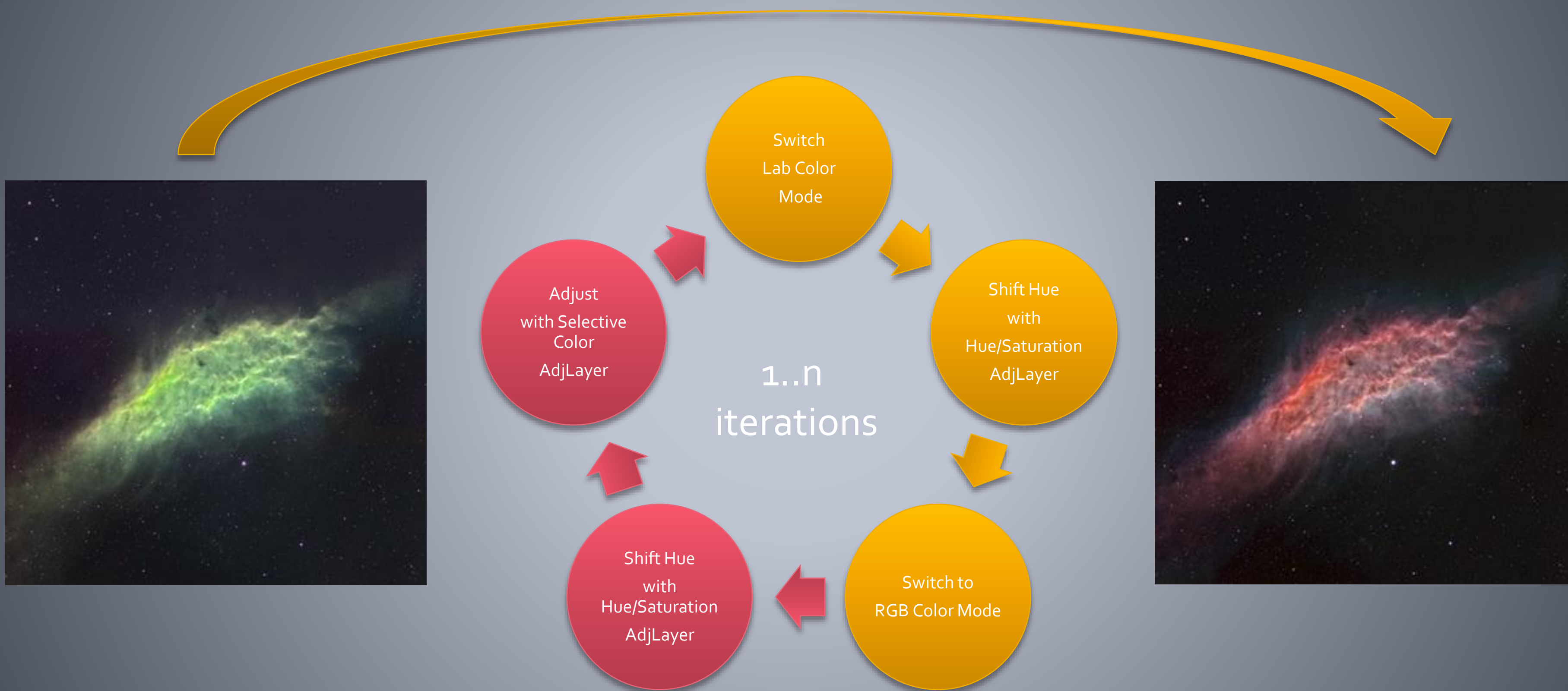
Move Hue slider to the opposite side (magentas)



- Flatten the image
- Image->Mode->RGB Color

Composing advanced LRGB images in false colors

Creating chrominance master frame



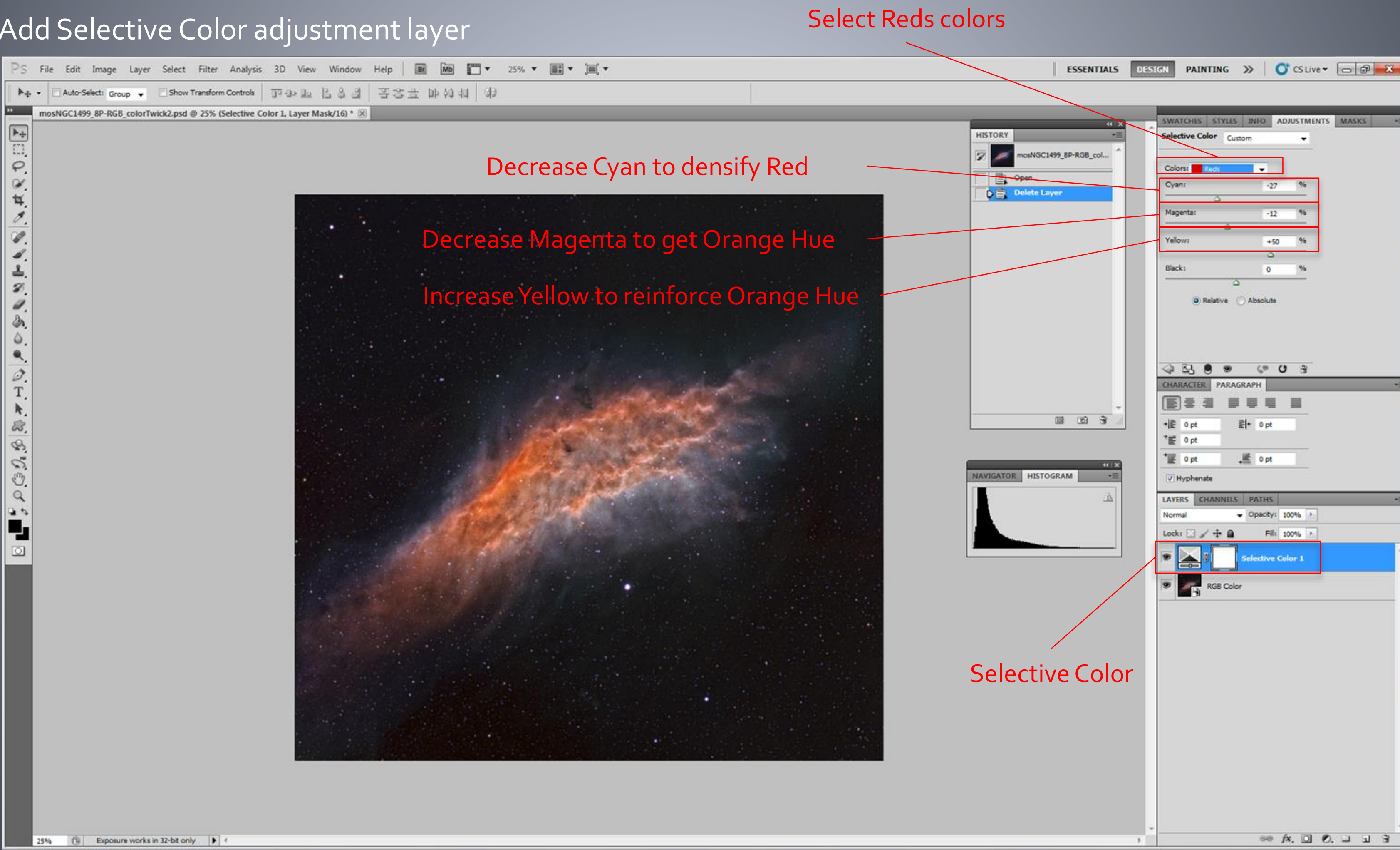
Mandatory steps

Steps required only if there is more than one iteration

NOTE: Sometimes to get good colors you must slightly switch the green hue to red hue within more that one iteration

Composing advanced LRGB images in false colors
Creating chrominance master frame

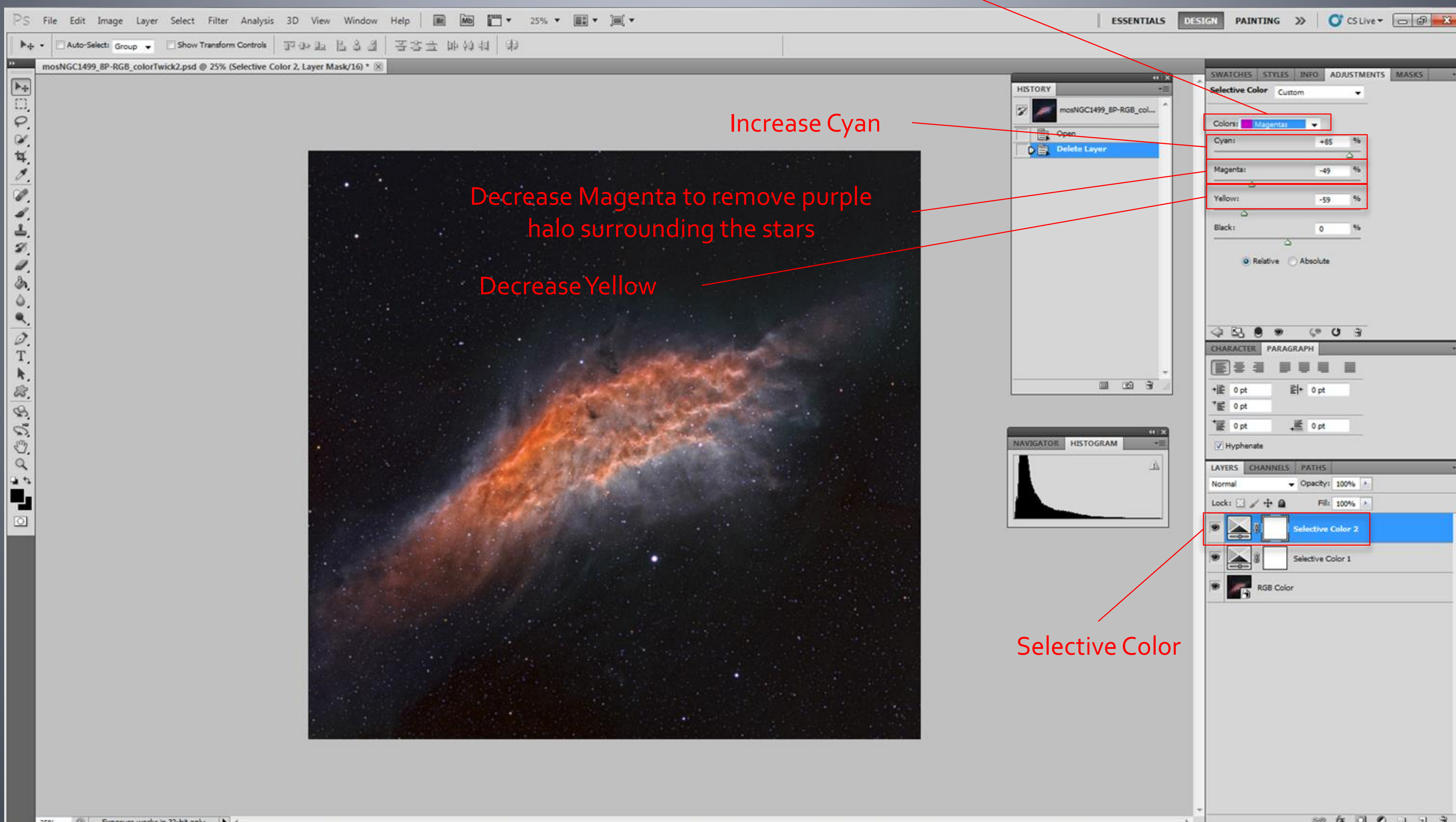
- Add Selective Color adjustment layer



Composing advanced LRGB images in false colors

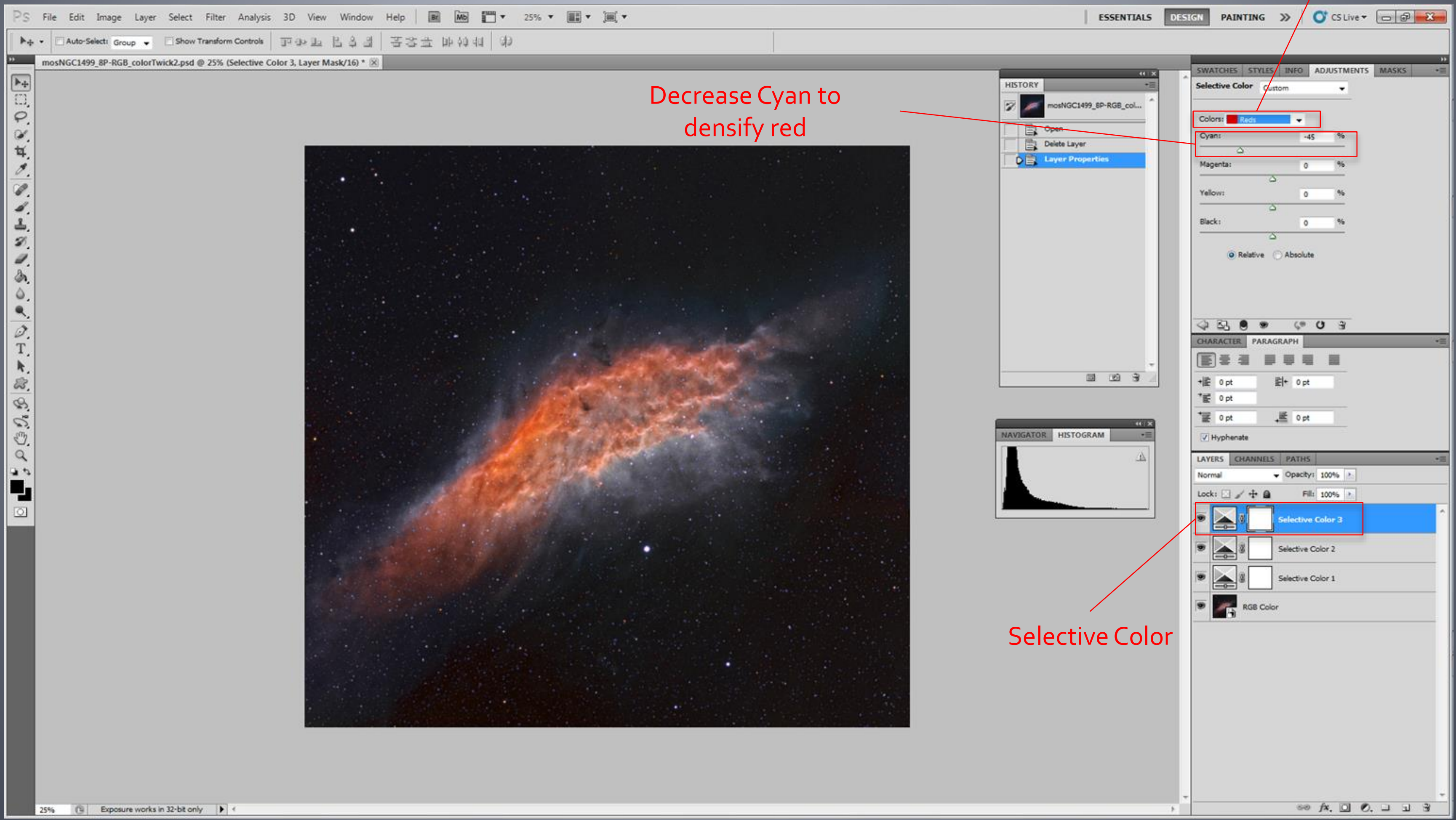
Creating chrominance master frame

- Add a second Selective Color adjustment layer



Composing advanced LRGB images in false colors
Creating chrominance master frame

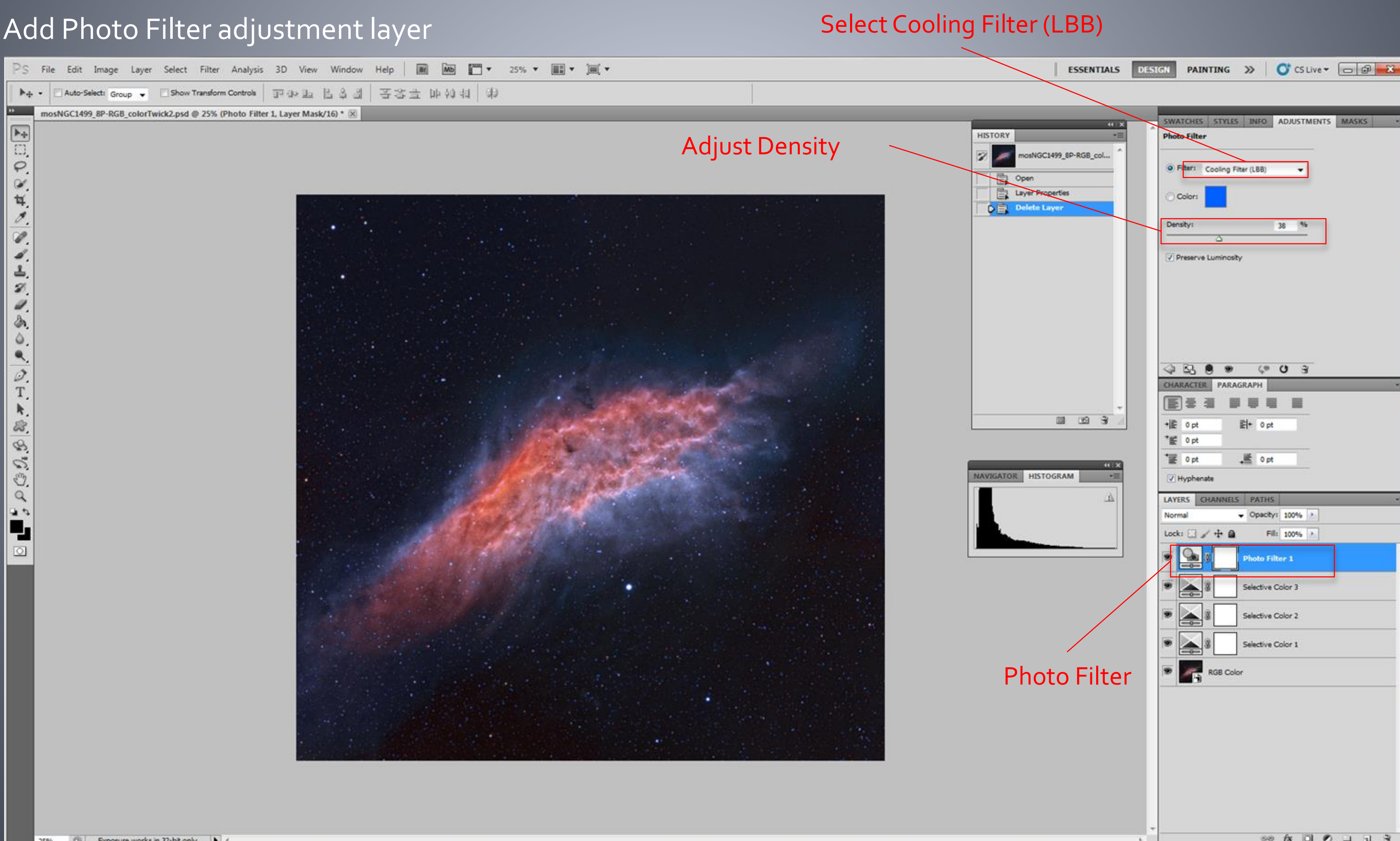
- Continue to add more Selective Color adjustment layers until you get the expected hue



Composing advanced LRGB images in false colors

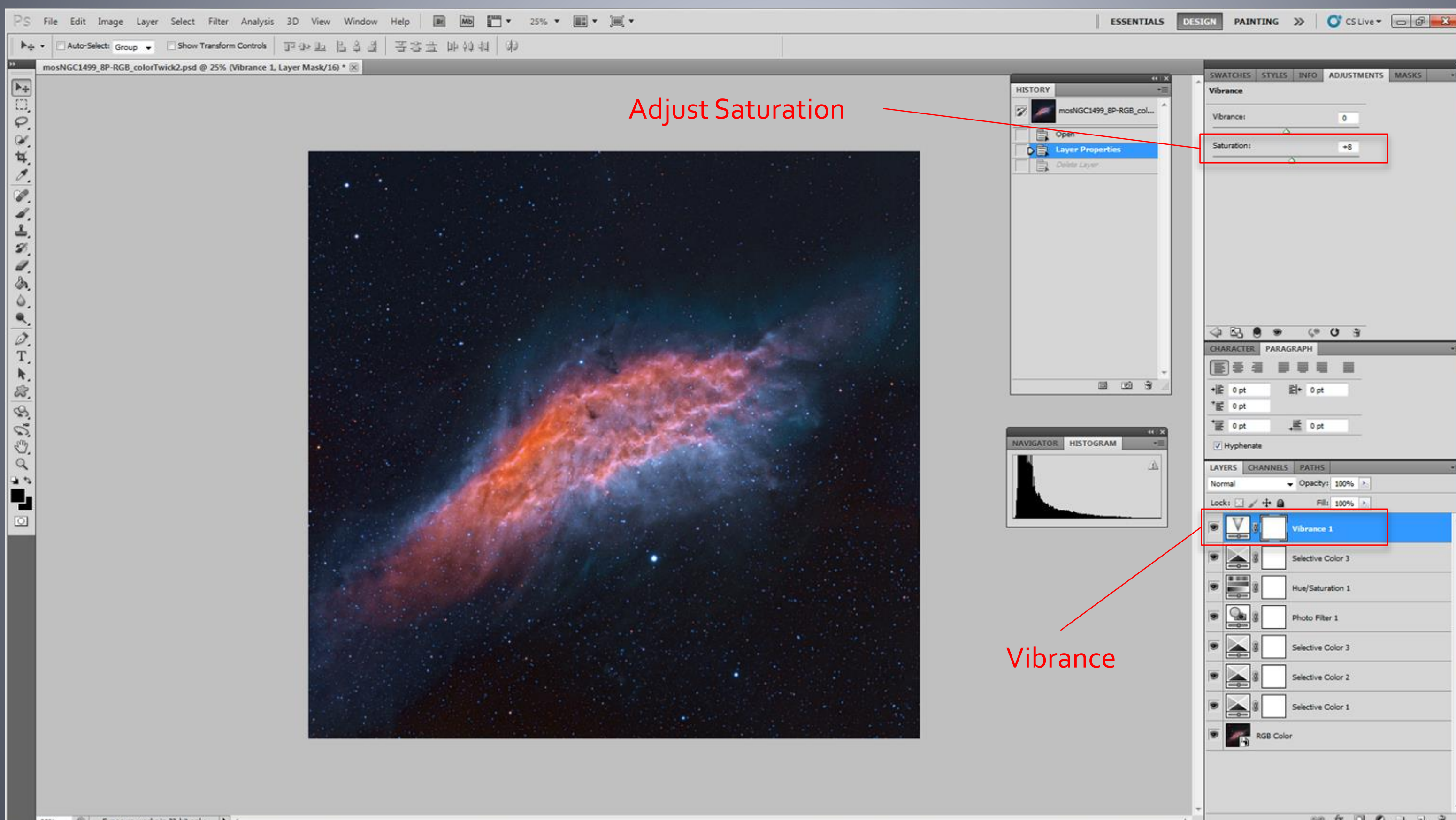
Creating chrominance master frame

- Add Photo Filter adjustment layer



Composing advanced LRGB images in false colors
Creating chrominance master frame

- Add Vibrance adjustment layer



- Flatten the image
- Save image to mosNGC1499_8P-RGB.tif

Composing advanced LRGB images in false colors
Creating chrominance master frame

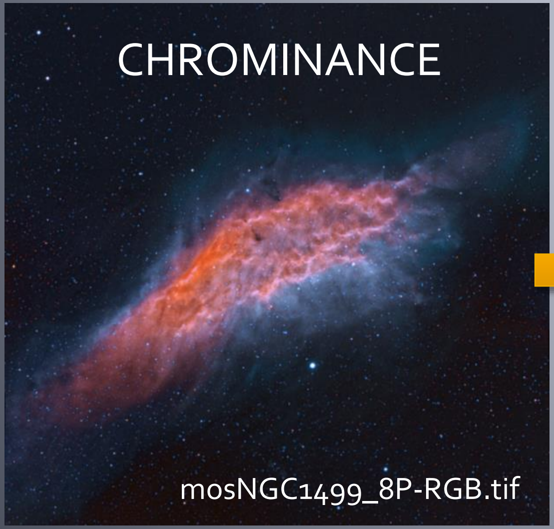
At this level the chrominance is done.

Bubble Nebula

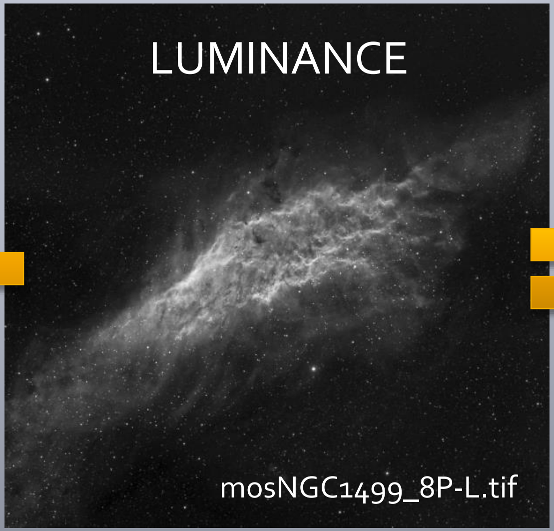
Chapter 12: Blending luminance with chrominance

Composing advanced LRGB images in false colors
Blending luminance with chrominance

- LRGB composition allows to blend luminance with chrominance
- Luminance brings the structural details
- Chrominance brings the colors



+

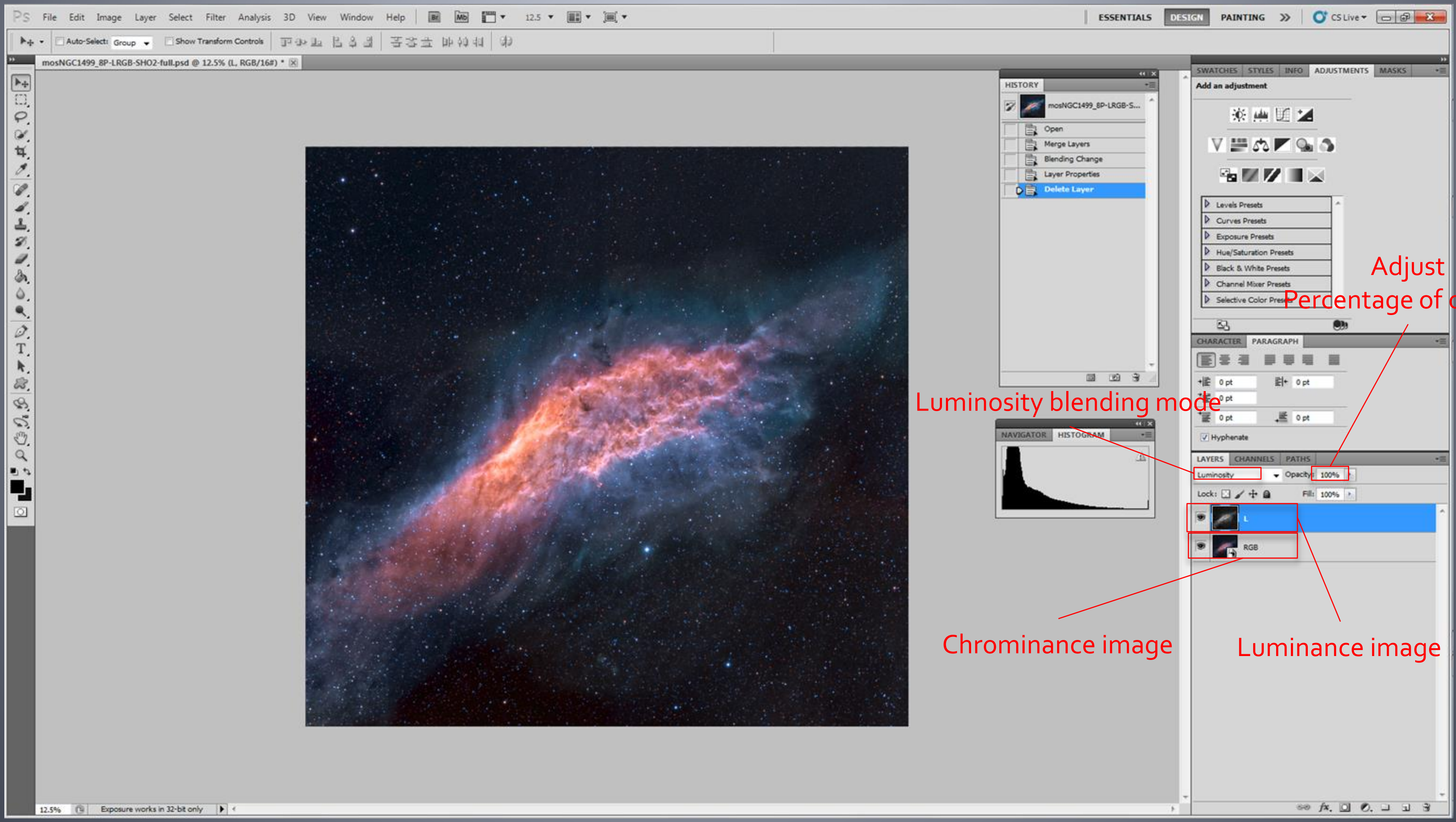


=

Composing advanced LRGB images in false colors

Blending luminance with chrominance

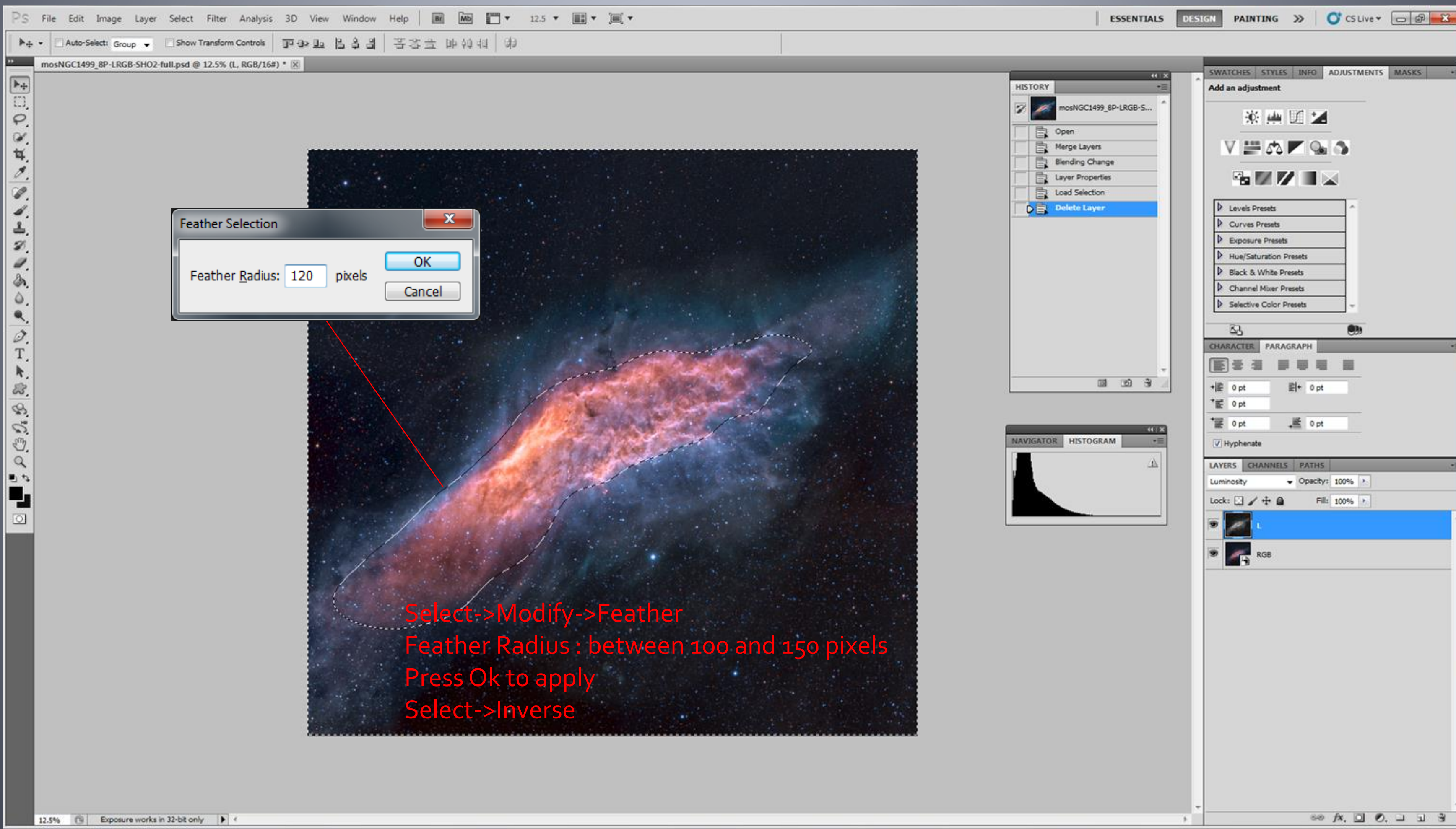
- Open chrominance image mosNGC1499_8P-RGB.tif
- Place the luminance image mosNGC1499_8P-L.tif on top of the chrominance image



Composing advanced LRGB images in false colors

Blending luminance with chrominance

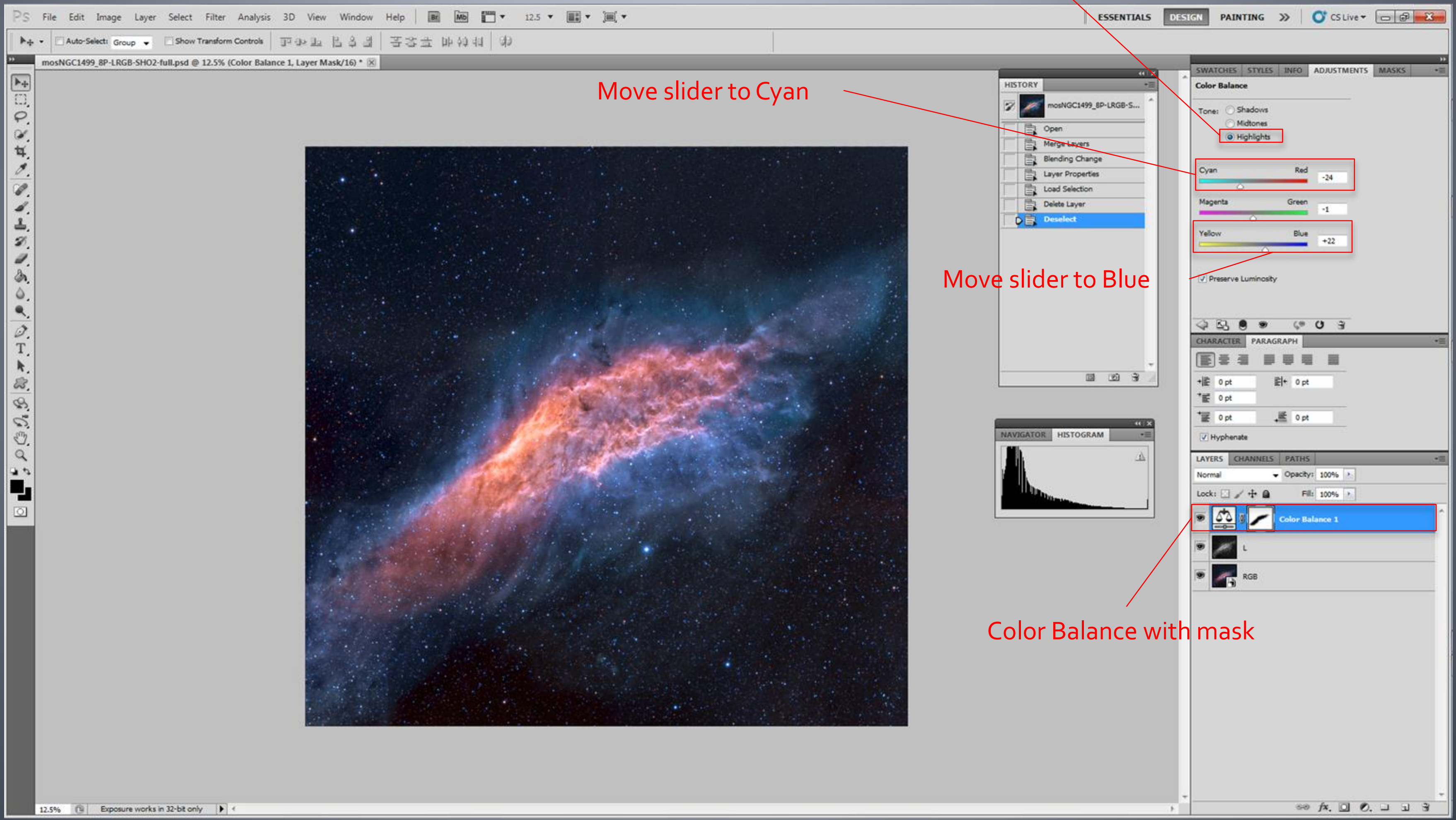
- Select the orange region with the lasso tool



Composing advanced LRGB images in false colors

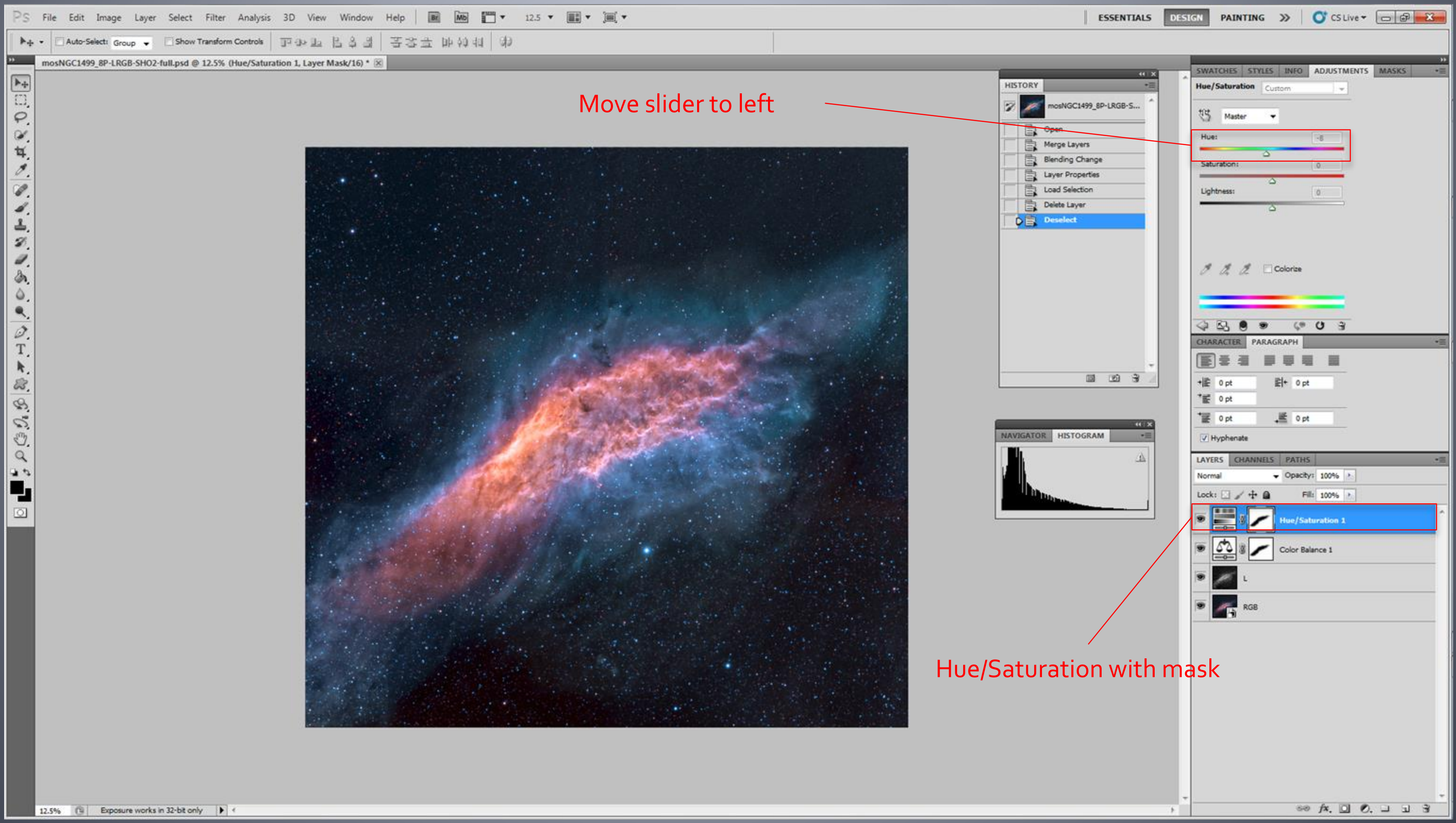
Blending luminance with chrominance

- Add Color Balance adjustment layer with the selection as mask



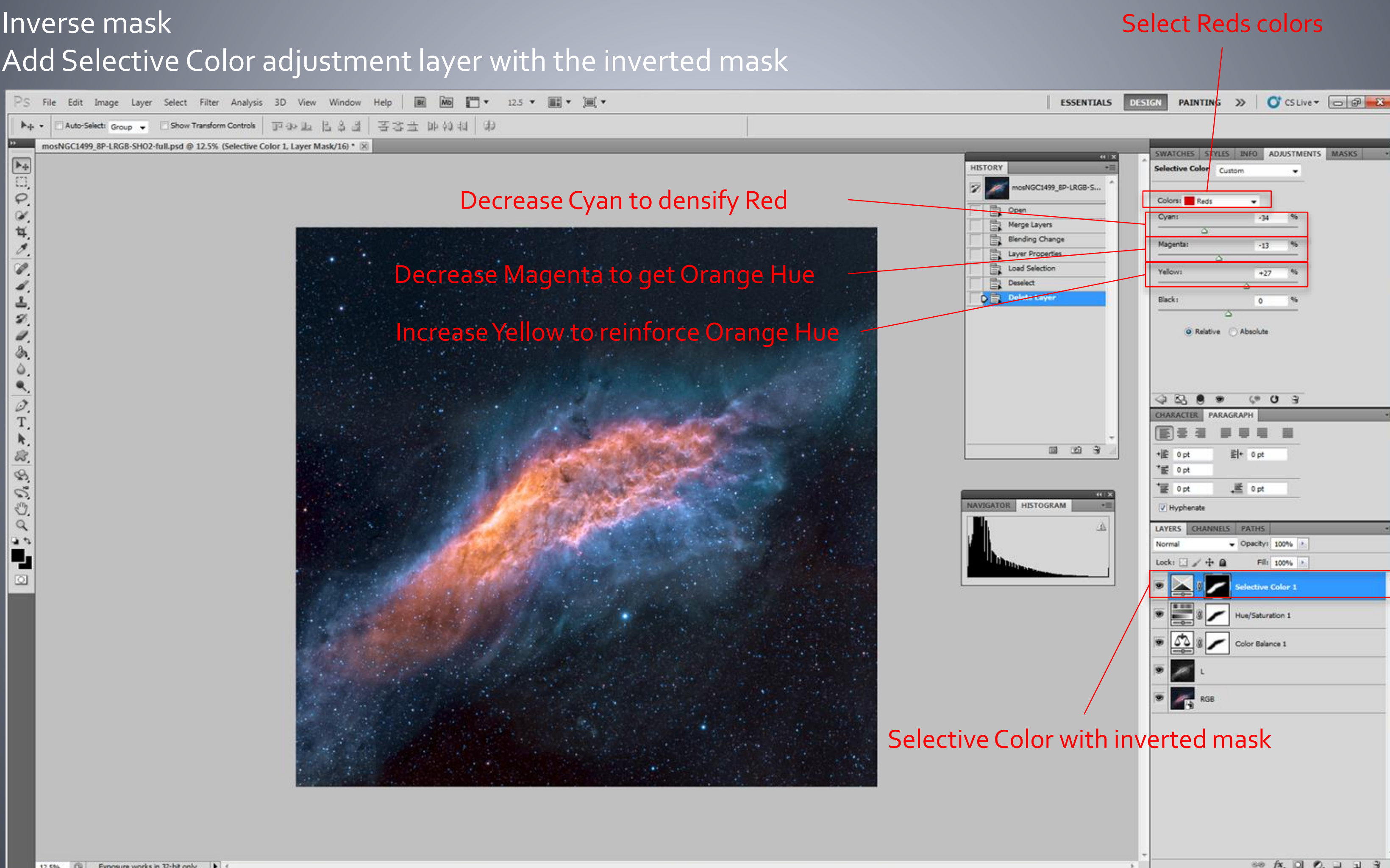
Composing advanced LRGB images in false colors
Blending luminance with chrominance

- Add Hue/Saturation adjustment layer with the same mask



Composing advanced LRGB images in false colors
Blending luminance with chrominance

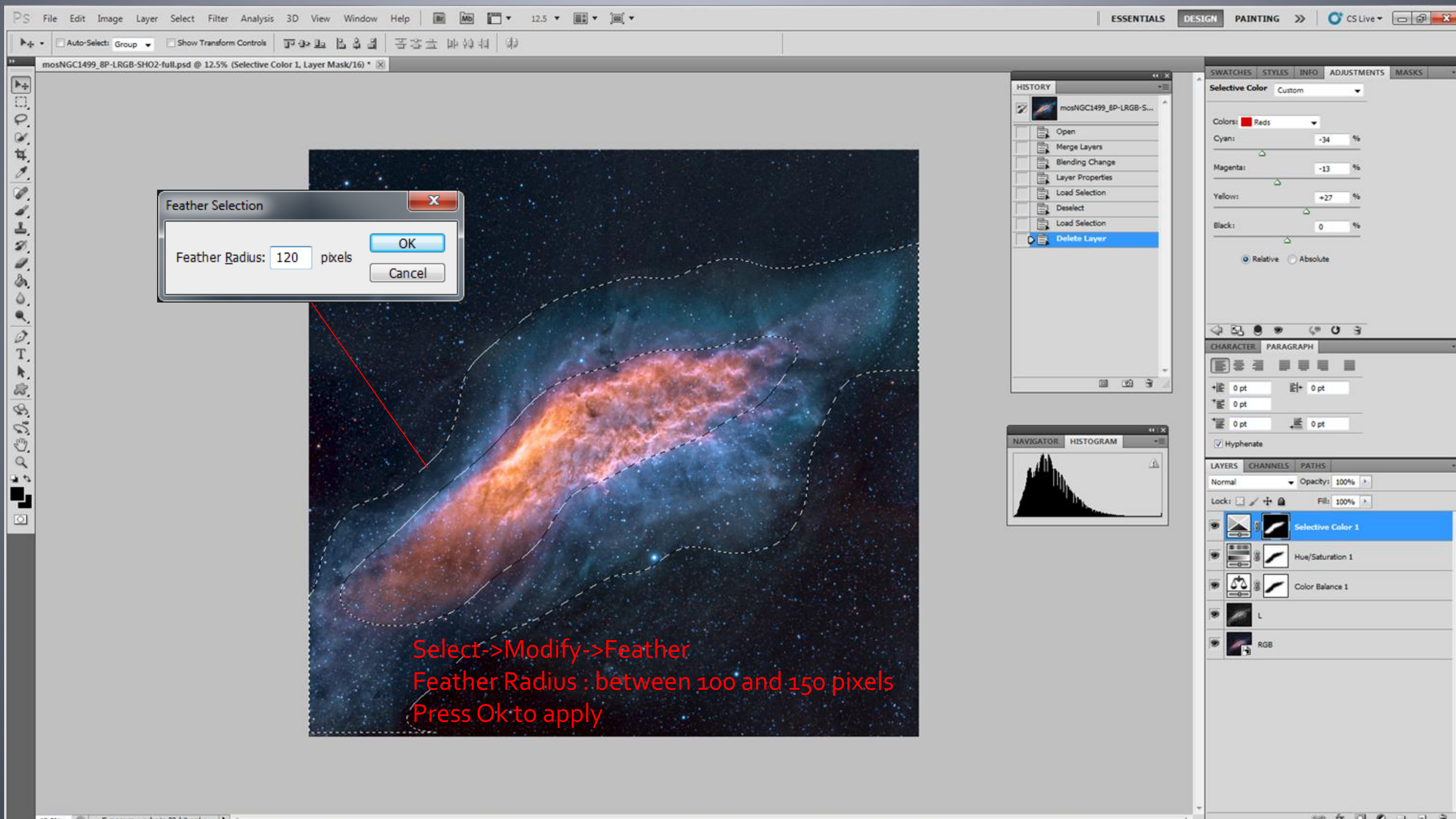
- Inverse mask
- Add Selective Color adjustment layer with the inverted mask



Composing advanced LRGB images in false colors

Blending luminance with chrominance

- Select the blue region of the nebula with the lasso tool

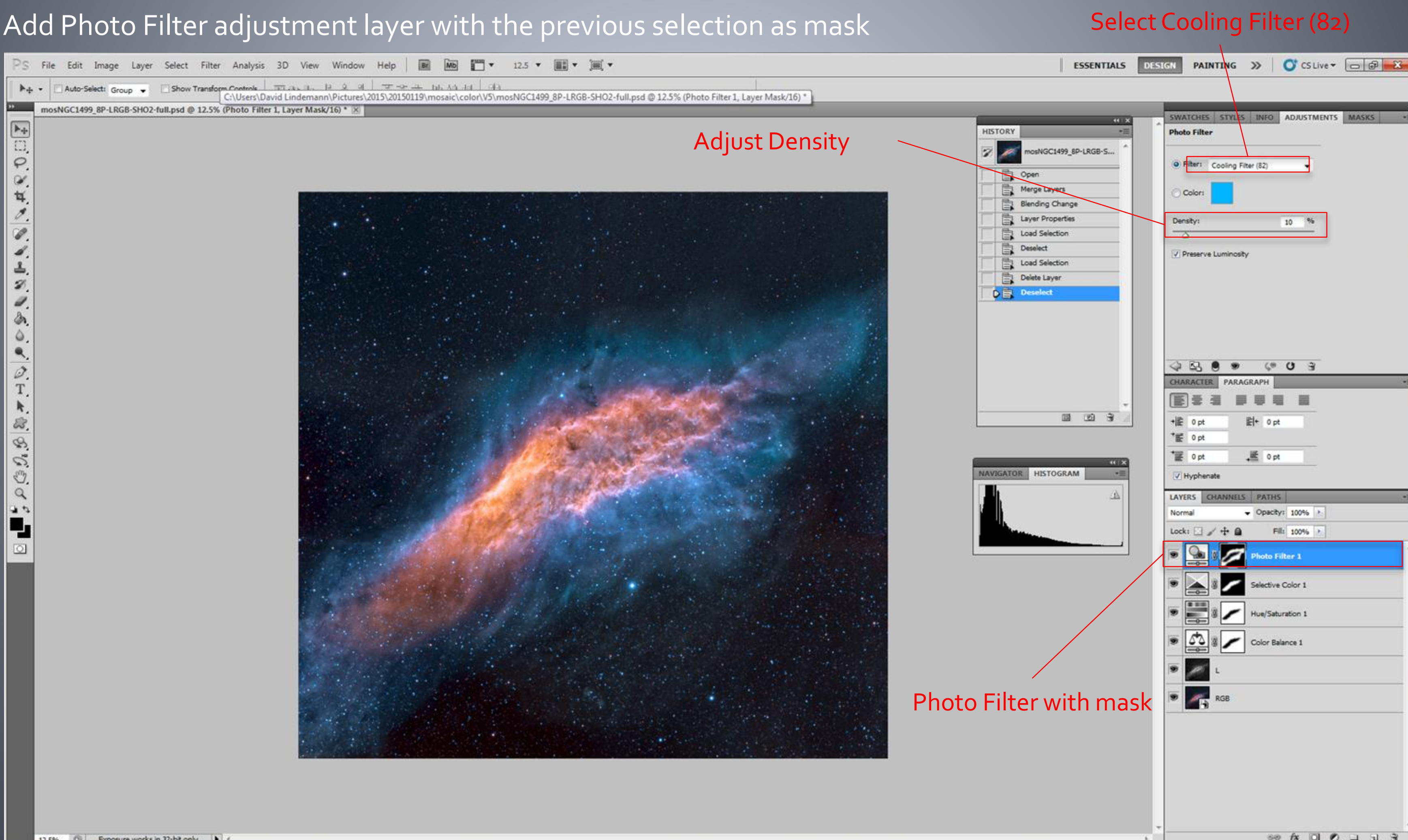


Composing advanced LRGB images in false colors

Blending luminance with chrominance

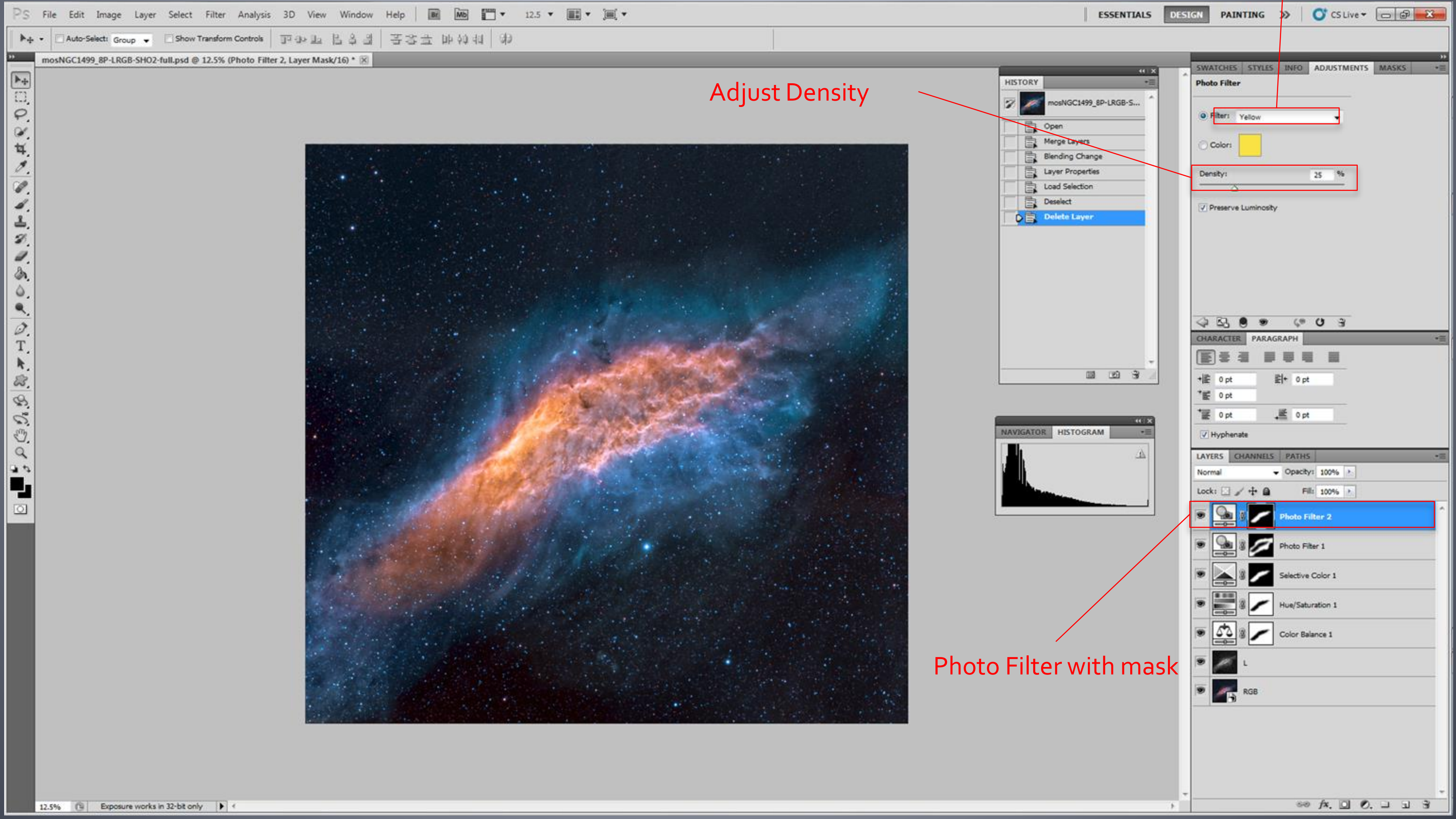
CEDIC

- Add Photo Filter adjustment layer with the previous selection as mask



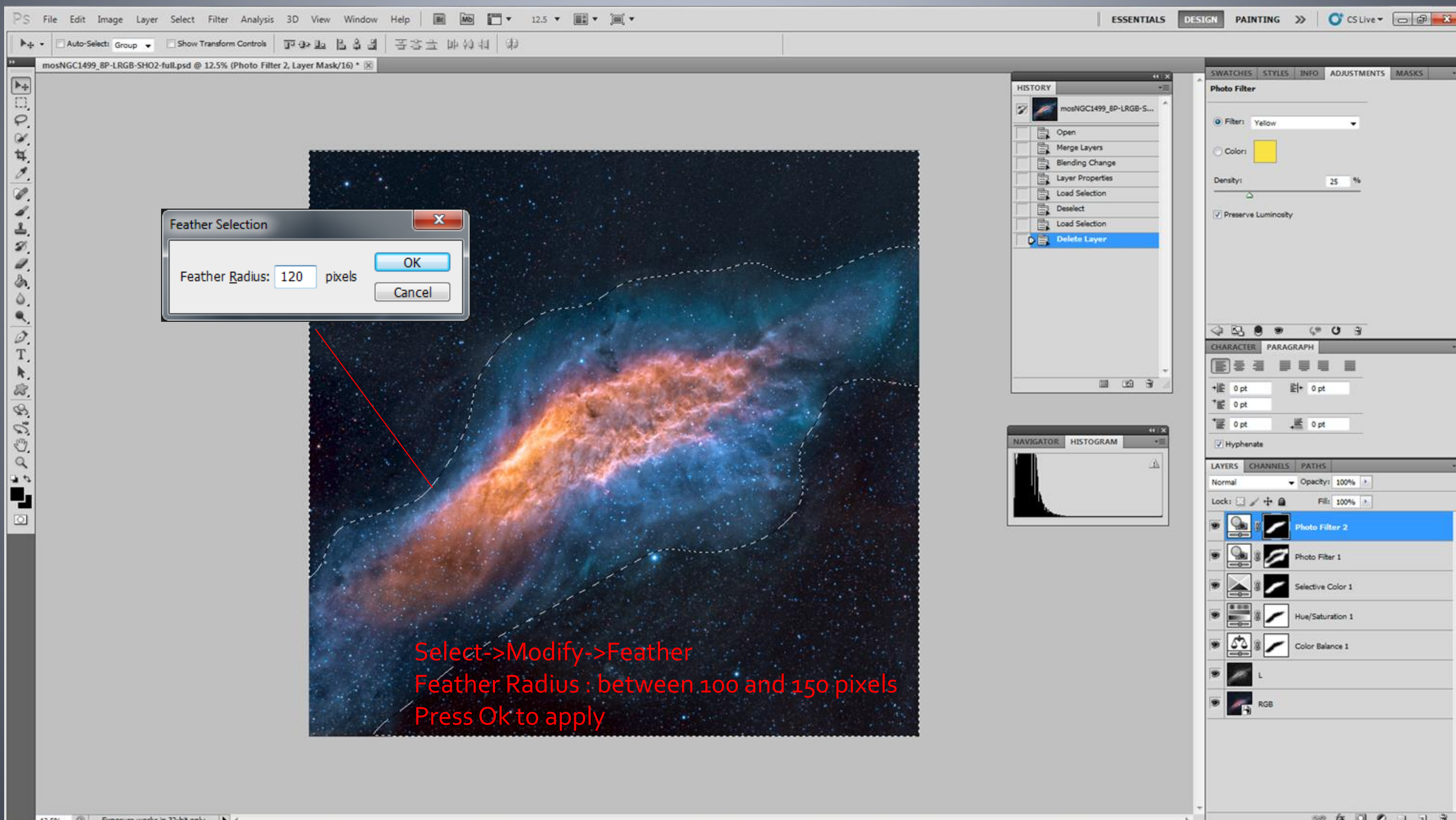
Composing advanced LRGB images in false colors
Blending luminance with chrominance

- Add Photo Filter adjustment layer with the mask that select only the orange area



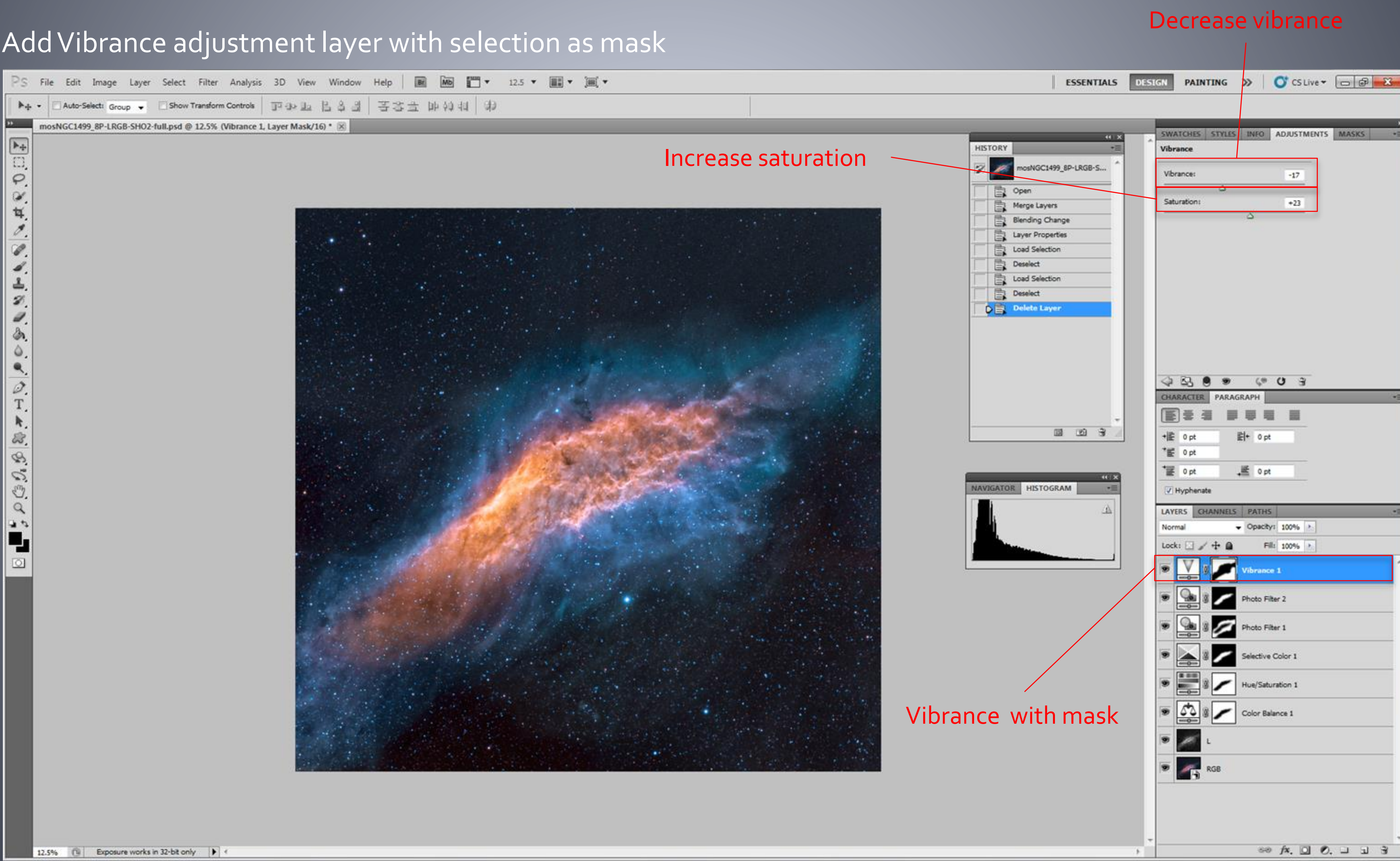
Composing advanced LRGB images in false colors
Blending luminance with chrominance

- Select the nebula with the lasso tool



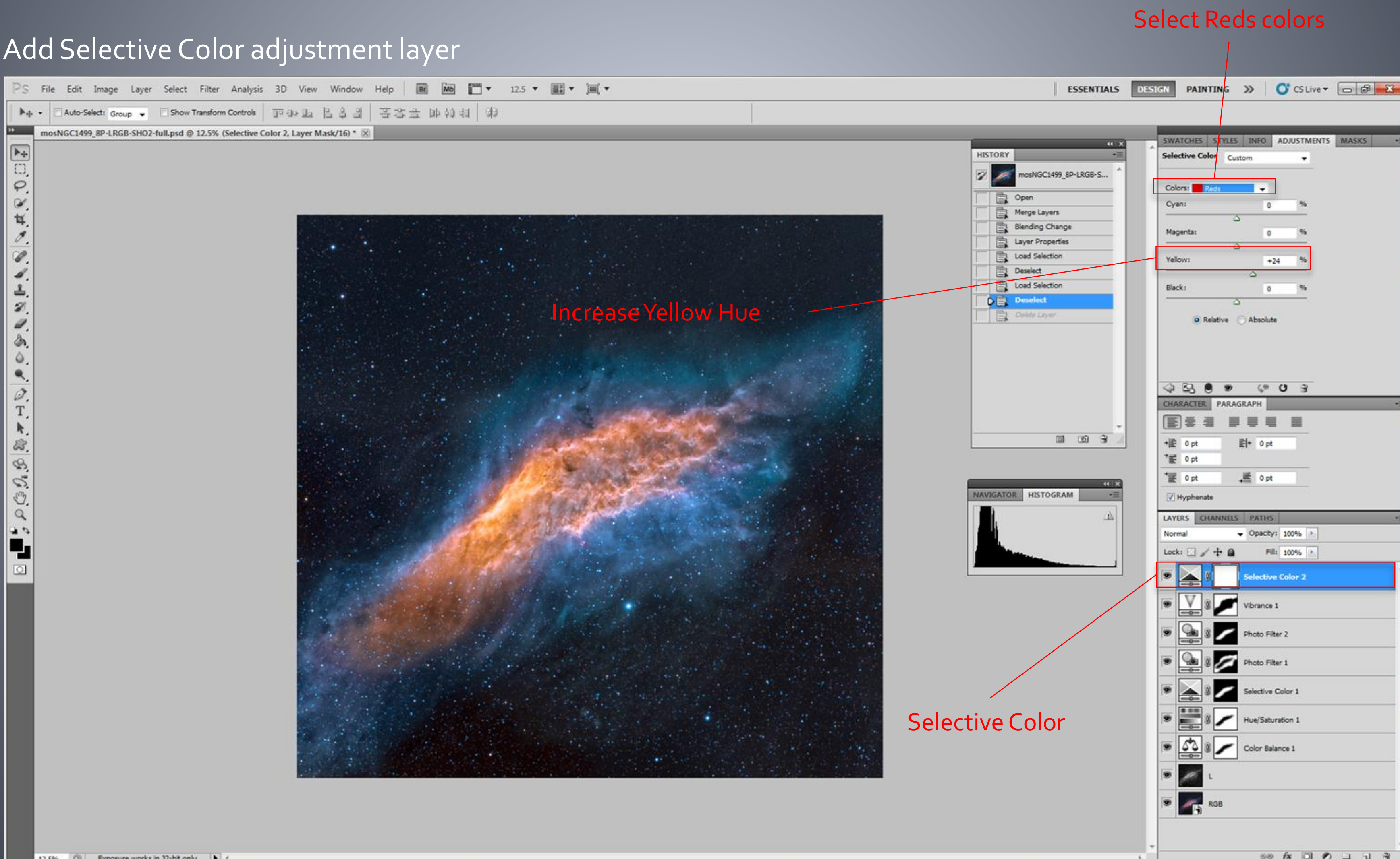
Composing advanced LRGB images in false colors
Blending luminance with chrominance

- Add Vibrance adjustment layer with selection as mask

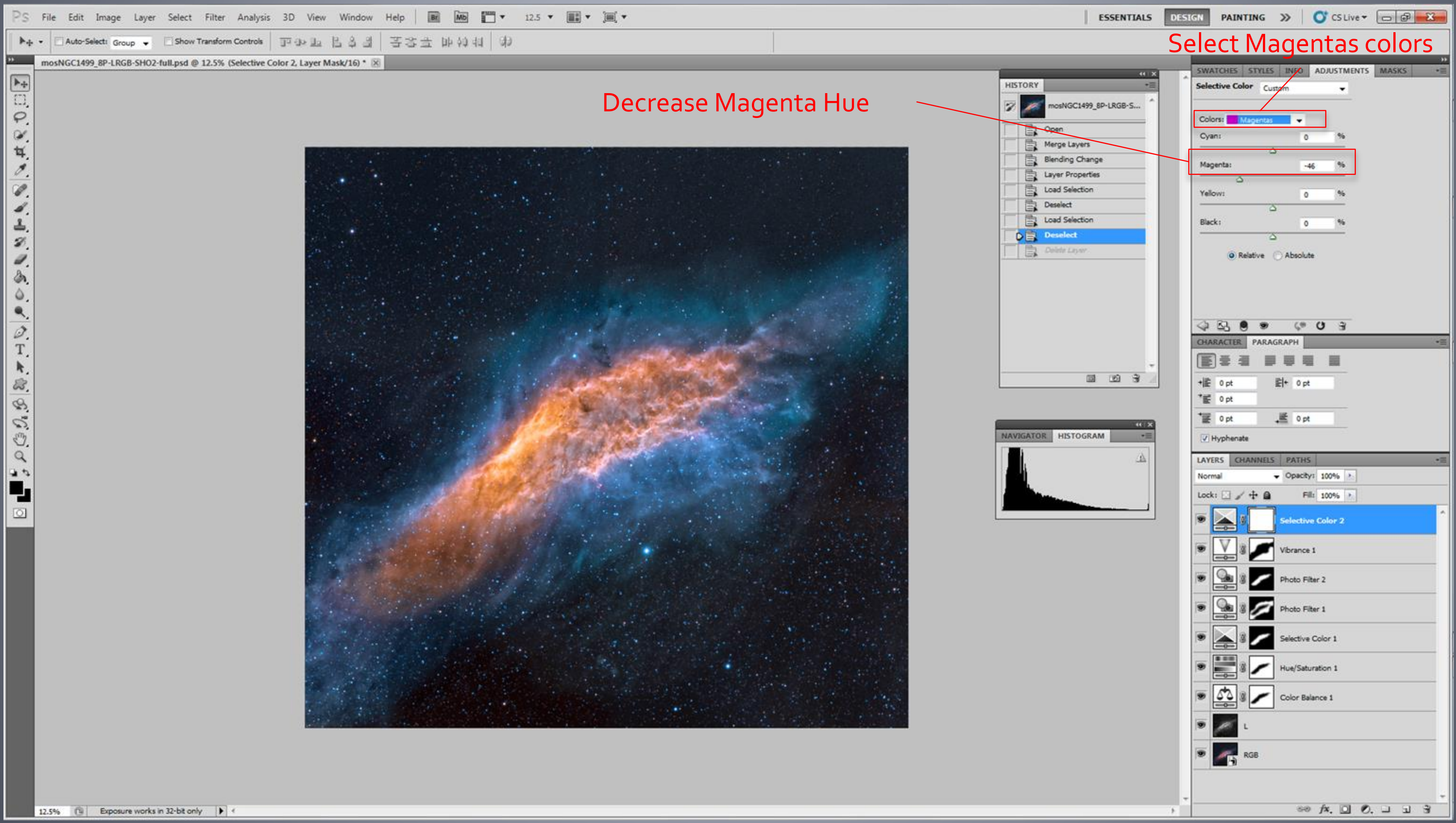


Composing advanced LRGB images in false colors
Blending luminance with chrominance

- Add Selective Color adjustment layer



Composing advanced LRGB images in false colors
Blending luminance with chrominance



- Flatten the image
- Save the image to mosNGC1499_8P-LRGB-SHO.tif

Composing advanced LRGB images in false colors
Blending luminance with chrominance

At this level the LRGB composition is done.

Composing advanced LRGB images in false colors

Some internet links where you can see some of my images

https://www.facebook.com/david.lindemann.92

http://www.astrobin.com/users/dlindemann/

http://deepskyentropy.blogspot.ch/

Thank you for your attention ☺