

Astrophotography Image Stacking

The Woodlands Camera Club
Post Processing SIG
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What is Image Stacking

- Image stacking is taking several photos and blending them together for a better combined image. Stacking comes in various forms,
 - HDR (high dynamic range) resolves exposure problems in highlights and shadows
 - Focus stacking creates greater depth of field than a lens will physically produce in one image
 - **Astrophotography stacking primarily reduces noise, but also increases contrast, color and detail**
- Technically, astro stacking increases the signal-to-noise ratio
- Noise grows at a slower rate than the signal, so very long exposures produce higher signal-to-noise ratios, meaning cleaner, smoother, more detailed images
- However, very long exposures are challenging due to earth rotation
- Short exposures miss the dimmest details
- Stacking many images is an alternative approach to very long exposures
- Noise tends to appear randomly across images. Averaging many images removes random noise and sensor noise, while retaining the original signal, which remains consistent across the images
- More images are better.
 - “20 images is ideal, any number over 5 will give noticeable improvements.”
 - “8 images is a sweet spot for beginner stacking.”

Primary source:

<https://www.skynightmagazine.com/astrophotography/astrophoto-tips/a-guide-to-astrophotography-stacking/>

Why Stack?

What problems are we trying to solve?

- **Star trails:** typical night time exposures at low ISO settings require several or even many minutes, but to avoid star trails from earth rotation the exposures must be much shorter. According to the 500 rule ($500/\text{focal length} = \text{maximum exposure in seconds}$):
 - 14mm = 35 seconds max.
 - 600mm = < 1 second max.
- **Noise:** low star light and small apertures in long lenses demand higher ISOs, which increase noise
- **Low contrast:** light pollution reduces contrast

Solutions:

	<u>Cost</u>	<u>Impact</u>
• Faster, better “astrophotography” lenses (Sigma 14/1.8 \$1,600; Sony 600/4 \$13,000)	\$\$-\$\$\$	L
• Better, newer sensors – may require a newer camera	\$\$\$	L
• High elevations and dark skies (Big Bend, Mauna Loa) – requires travel, time	\$\$-\$\$\$	M
• Larger pixel or dedicated astro sensors – requires a dedicated camera	\$\$\$	M
• “Star trackers” (equatorial mounts, guided trackers) – requires equipment ⁽¹⁾	\$\$-\$\$\$	H
• Stack multiple images together in post processing to reduce noise and increase contrast, dynamic range and saturation – requires time, software	Free - \$\$	H

Conclusion:

- With the highest benefit and lowest cost, image stacking is an **essential** part of astrophotography

⁽¹⁾ Milky Way time lapse using a tracker <https://www.youtube.com/watch?v=1zJ9FnQXmJI>



WWW.ADAMWOODWORTH.COM

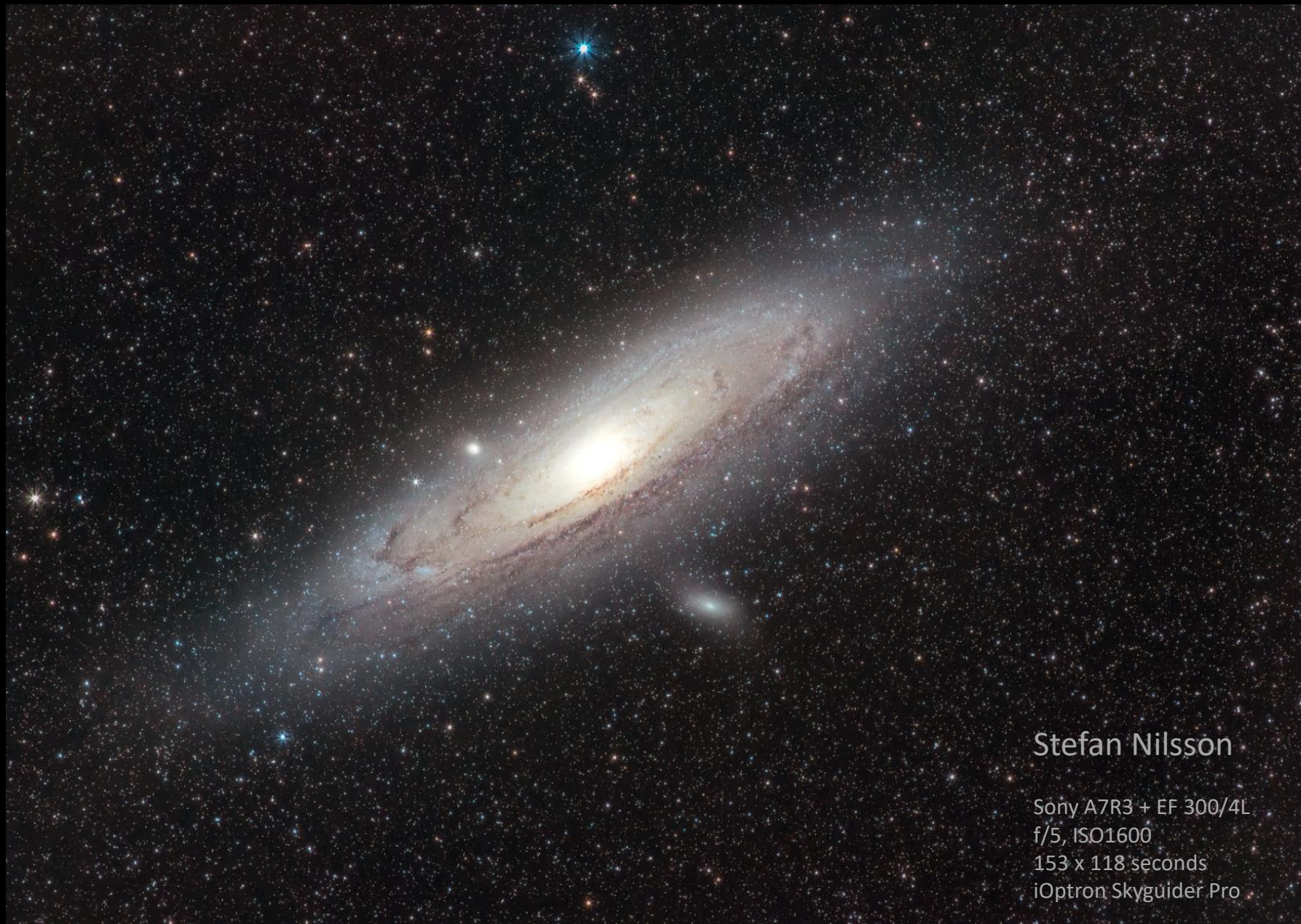
Adam Woodward

<https://adamwoodworth.com/blog/milky-way-and-dead-trees-2/>



Imma Barrera

<https://www.worldphoto.org/ru/sony-world-photography-awards/winners-galleries/2019/professional/under-night-sky-imma-barrera>



Stefan Nilsson

Sony A7R3 + EF 300/4L

f/5, ISO1600

153 x 118 seconds

iOptron Skyguider Pro



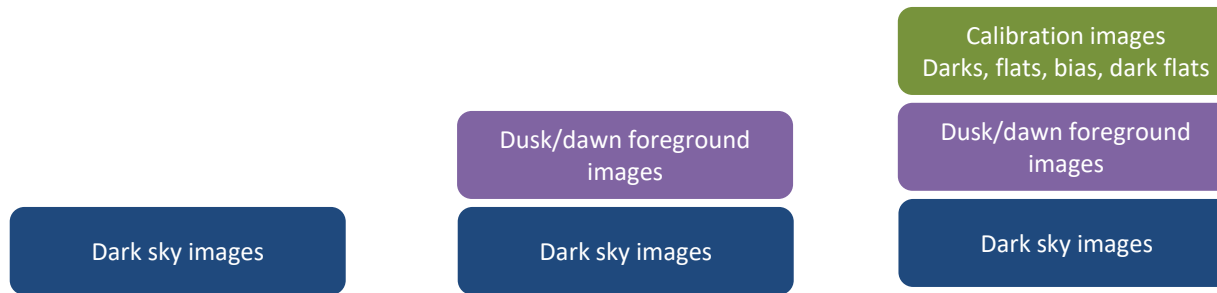
Patryk Sadowski

A7Riii, 200-600, 2x TC,
Star Adventurer

30 images light side
20 images dark side

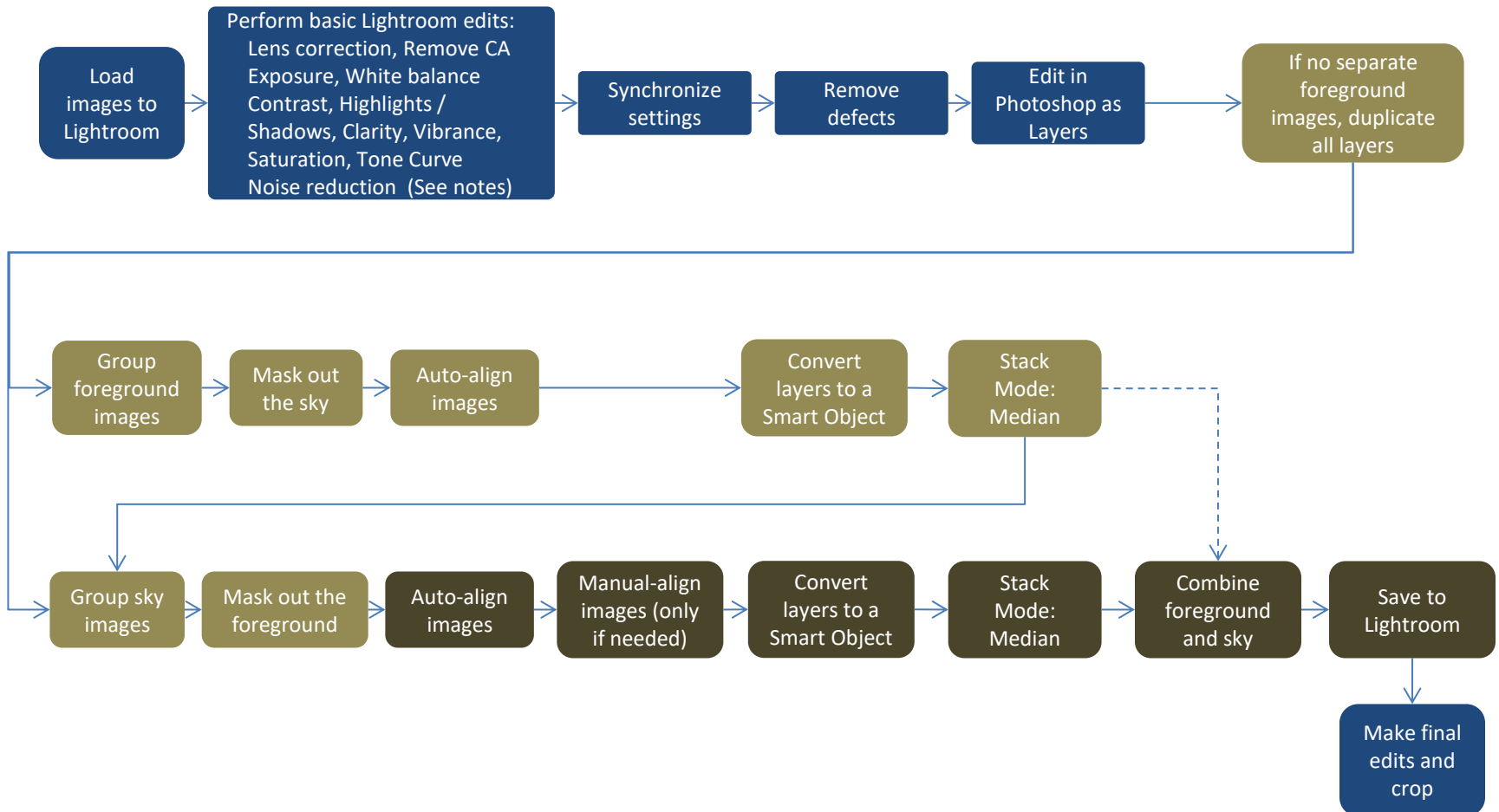

PATRYK SADOWSKI
PHOTOGRAPHY

Image Capture Workflows



- Single image – works best in very dark conditions; no benefit from stacking.
- Multiple images, same foreground exposure as sky, or no foreground (e.g. comet, moon, M31)
 - Take 8 or more RAW dark sky photos using a tripod
 - In post processing duplicate the images, process foreground and sky independently, then recombine
- Multiple images with different exposures for foreground and sky
 - Take RAW foreground photos at dusk using a tripod; then wait until dark to take 8 or more sky photos; don't reframe the image between dusk and dark
 - Process foreground and sky independently and combine for a composite image
 - Note: reverse the order for dawn images: sky first in the dark then foreground in the dawn
- Multiple images using advanced software and stacking techniques
 - Add calibration images (see notes)

Post Processing Workflow Summary (for Lightroom and Photoshop only)



Legend:



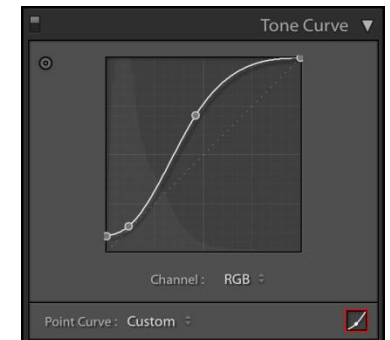
Editing Milky Way Images in Lightroom

This work flow is from Ian Norman at LonelySpeck.com. There are many other, different workflow tutorials available free on the web and in YouTube.

<https://www.lonelyspeck.com/how-to-process-milky-way-astrophotography-in-adobe-lightroom/>

In Lightroom pick one image to edit, which will be the template for the whole stack.

- Exposure: Set the exposure to reveal shadow detail in the foreground (if you have one). Note: Modern sensors can pull much more detail from under exposed images, but over exposed highlights can't be recovered. When taking the photo it's better to under expose than over expose.
- White Balance Temperature and Tint:
 - **Temporarily increase the Vibrance and Saturation all the way to +100.** This will make the image look completely oversaturated but should make it easier to balance temperature and tint.
 - Adjust white balance; 3900K is typical. Daylight setting will typically cause an orange tint, but you must also balance light pollution, airglow and star color.
 - Set the blue – orange/yellow slider to neutral, then set the tint slider to balance green-pink to neutral.
 - Then return Vibrance and Saturation to zero.
- Contrast: adjust to bring out more detail. If this changes the exposure and that should be revisited now. Watch for and avoid vignetting as these settings change.
- Highlights and Shadows: Prevent over exposure of whites. Revisit overall exposure if needed.
- Clarity, Vibrance and Saturation: higher settings will bring more detail, but too much will create halos and a fake appearance, as well as noise. Add a little but keep these below 50.
- Tone Curve: choose the point curve version by clicking on the box in the lower right corner (shown here in red).
 - **Bring up the far left black point a bit**
 - **Add a dark point and bring the rest of the black curve down to the center line**
 - **Add a point in the middle of the curve and increase it for brighter highlights**
- Basic Noise Reduction: Typically set Luminance noise reduction between 20% and 50%; higher Luminance noise reduction reduces image detail. Increasing the Detail slider and Contrast slider can compensate for the “muddying” effect that Luminance noise reduction can create. Default Color noise reduction is usually fine (Color 25, Detail 50, Smoothness 50).
- Go to the grid view, select all of the images, and synchronize settings (lower right corner button) across the whole stack.
- Remove any defects such as planes and satellites from each image individually.
- Select all of the images again.
- Right click, Edit In, open as layers in Photoshop then sit back and wait.



Processing and Stacking Milky Way Images in Photoshop

Foreground

- If you don't have a separate group of foreground images, duplicate all of the layers. You want a stack of images for the foreground, and another stack for the sky.
- Select all of the copies you just made - these will be the foreground - and convert them to a smart object. All of the images will be combined into one image.
 - If you get a burred foreground you may need to back up. Undo the smart object, pick a layer, make a layer mask and mask out the sky, then copy this mask to the other foreground layers, then auto-align the layers, then convert them to a smart object.
- Merge the foreground data. Select that smart object image, then click [Layer, Smart Objects, Stack Mode, Median]. The sky should be blurred, but the foreground should be sharp.
- Rename the smart object to "foreground" and drag it to the bottom of the layer list.

Sky

- Select the top layer sky image (turn off the others), add a layer mask, and mask out the foreground using a large paintbrush tool, black paint, and a soft edge on the brush.
- Copy the layer mask to the other sky images by holding <CTRL> <ALT> and dragging it to the next image. Do this repeatedly until all of the sky images have the mask. Don't do this for the foreground.
- Turn on all of the sky layers
- Try the auto-alignment feature. Select all of the layers. Then [Edit\Auto-Align Layers\Auto]. The auto project method usually works best, but you can try others.
- Check each layer to ensure they are all aligned by turning them on/off one at a time. If not, they'll need to be aligned manually (next page).
- Select all of the layers and combine them into one smart object layers: [Layer\Smart Objects\Convert to Smart Object].
- Then select the Median smart object stack mode: [Layer\Smart Objects\Stack Mode\Median].

Combine and Finish

- Combine the Foreground and Sky layers and save back to Lightroom for final touchup and crop.

[\(1\) https://www.lonelyspeck.com/how-to-process-milky-way-astrophotography-in-adobe-lightroom/](https://www.lonelyspeck.com/how-to-process-milky-way-astrophotography-in-adobe-lightroom/)

Processing Milky Way Images in Photoshop – Manual Alignment

Manual Alignment (needed only if auto-alignment fails)

- Select only the bottom sky layer (which should be above the combined foreground layer). This layer will be the reference for aligning all of the other sky layers.
- Now also select the layer next to i.e. above the bottom layer; this will be the first layer that is manually aligned to the reference.
- In the drop down box of the Layers tool (right side, just above the layer list) change the layer type from [Normal] to [Difference]. In this Difference mode when the two layers are perfectly aligned the screen will be black. If not aligned you'll see white or other colors.
- Ensure the snap function is disabled / unchecked. Select [View \ Snap] which toggles the snap function on/off. The snap function may prevent perfect alignment.
- On the screen you are now looking at two layers on top of each other. The bottom layer is the reference layer, which you won't touch in this section, and you will now modify the top layer. Click [Edit\Free Transform] from the menu.
 - 1.Center: Zoom in to the center of the image and drag the whole top layer until the center portion of the image hides the reference layer below it. The screen will be black where the 2nd layer is perfectly hiding the 1st layer.
 - 2.Rotation: Navigate to any corner of the image. Grab the corner and rotate the whole image (pivoting around the center) until that corner it is aligned as much as possible.
 - 3.Corners: Now adjust each corner separately by holding <ALT> and clicking on the corner white square box; the cursor will change to a double arrow. Move the corner until it aligns as much as possible, then repeat for each of the other corners.
 - 4.Warp: Now add warp lines by clicking [Edit\Transform\Warp]. Hold down the <Alt> key and click the mouse to add blue warp lines. A 3x3 or 4x5 grid should be sufficient. This will allow you to tweak portions or quadrants of the image without affecting other sections.

Note: Consider converting each layer, independently to a smart object. If you warp a normal pixel layer, the changes you make become permanent. But if you warp a smart object, the warp remains editable. You can warp a smart object further if you need to, or undo the warp and return to the original shape of the image at any time, without any loss in quality.
 - 5.Review each quadrant and tweak it as necessary to improve alignment in that section. YOU DON'T NEED PERFECT ALIGNMENT. This process could distract an obsessive person for hours.
 - 6.When finished click the check mark in the upper center menu bar to apply the warp mode changes, or press <CMD/CTRL> <Enter>
- Change the layer type from [Difference] back to [Normal] in the Layer drop down box, and deselect this layer. This layer is aligned with the reference layer and you're done with this layer.
- Now repeat this process (steps 1-6 above) for each layer.

Before and after C/2020 F3 (Neowise) comet photos using these techniques

A7iii, 200-600/5.6-6.3 at 250mm
ISO 6400, F/6.3,
Star Adventurer
6 images x 20 sec. each



2:1 zoom comparison





Exercise #1: Moon

- No foreground
- Auto alignment

11 images x 1/200 sec
840mm, F/13, ISO 100
Sony A7iii, 200-600mm,
1.4x TC

2:1 magnification

- Auto stacked
- Same noise and sharpness

Single image

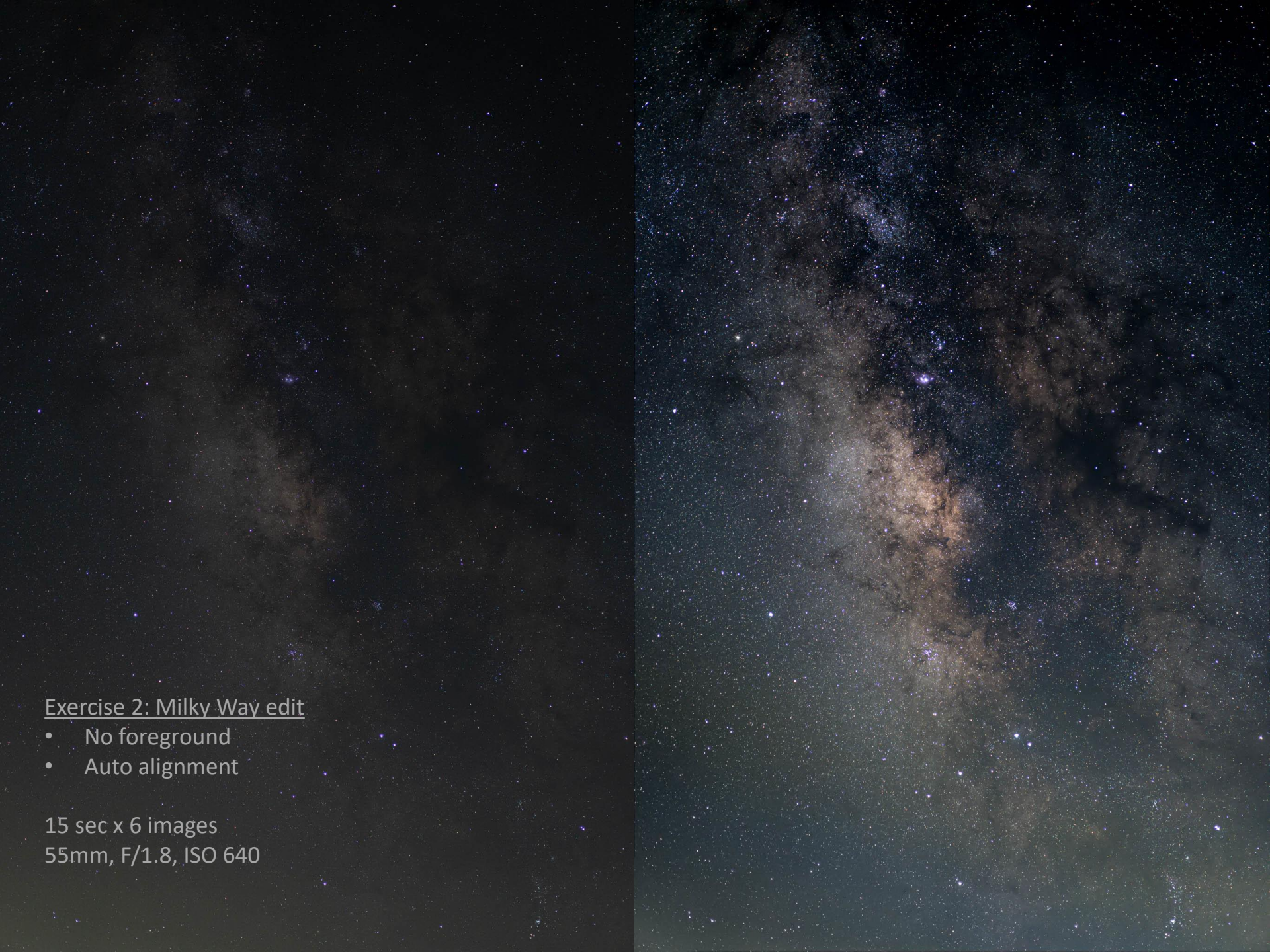
- More noise



Stacked image:

- More color
- More detail





Exercise 2: Milky Way edit

- No foreground
- Auto alignment

15 sec x 6 images

55mm, F/1.8, ISO 640



Exercise 3: Neowise Landscape

- Foreground
- Manual alignment

A7iii, 85/1.8

ISO 640, F/1.8,

Star Adventurer

6 images x 10 sec. each



First attempt, new lens:

- Only exposed for the sky
- Duplicated all images and pushed foreground +2.4 stops

10 images x 10-13 sec. each

15mm F/2

ISO 3200

Sony A7iii, Laowa 15/2

Flaming Gorge, UT



2nd Attempt

- Exposed for foreground first (error)
- Dawn started; missed the stars
- Clouds caused a lot of manual work

4 images x 13 sec

15mm, F/2

ISO 1600

Sony A7iii, Laowa 15/2

Grand Tetons



3rd Attempt

- Did not expose foreground separately, but processed it independently
- 7 images x 20 sec, 15mm, F/2, ISO 1600, Sony A7iii, Laowa 15/2, Death Valley

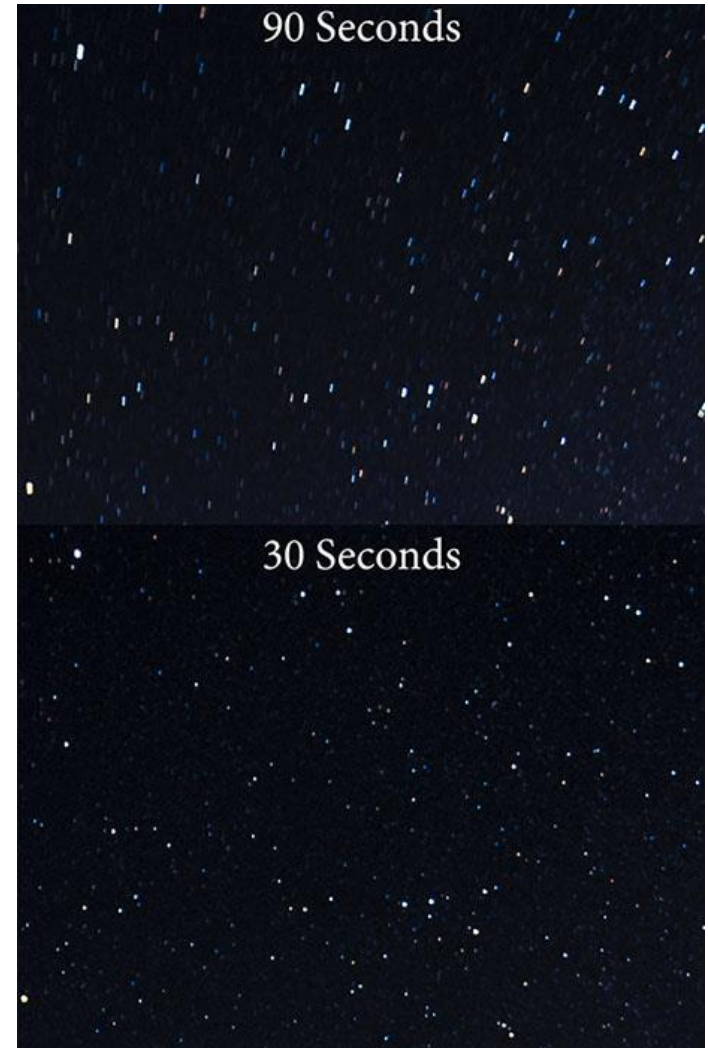
Appendix

The 500 Rule

500 divided by the focal length of your lens = the longest exposure (in seconds) before stars start to “trail”

For example if you’re taking a shot with a 24mm lens on a full frame camera. $500 / 24 = 21$ seconds, which you can round to 20 seconds.

Focal Length	Seconds Before Stars Blur		
	Full Frame	Nikon 1.5 Crop	Canon 1.6 Crop
10	n/a	33	31
14	36	24	22
16	31	21	20
20	25	17	16
24	21	14	13
28	18	12	11
35	14	10	9
50	10	7	6
70	7	5	4
85	6	4	4



Tips

- Turn **long exposure noise reduction off**, which essentially does in camera stacking by taking the shot twice. This might work in some situations but it doubles the exposure time, and only works if you have an good tracker.
- Turn **image stabilization off**. The lens may “hunt” during the exposure, causing motion blur.
- **Set exposure for the brightest part of the image**. Over exposed star detail can't be recovered, while an increasing amount of shadow can be recovered. Better to under expose than over expose.
- Assuming you'll have many photos to stack, deliberately underexposing the image is a good way to increase data without changing star trail blur.

Software

Post Processing Software

- Photoshop – powerful
- Lightroom – best for preliminary and final tweaks
- Deep Sky Stacker – best free option
- SiriL – free, robust
- GIMP – free, complicated
- Affinity Photo – user friendly, inexpensive
- PixInsight – best, perfect noise reduction and alignment, expensive
- StarTools – free, good for beginners
- Astro Pixel Processor – best post-processing tools
- Starry Landscape Stacker – free, long-time popular favorite
- Starry Sky Stacker – Mac only
- Sequator
- Nebulosity
- Pixinsight

Other Astrophotography Software:

Predict astro locations and times:

- Stellarium and Stellarium +
- PhotoPills
- Photographer's Ephemeris

Polar align your tracker:

- PS Align Pro

Misc.:

- LightPollutionMap
- ISS Detector
 - Emerald Sequoia Time

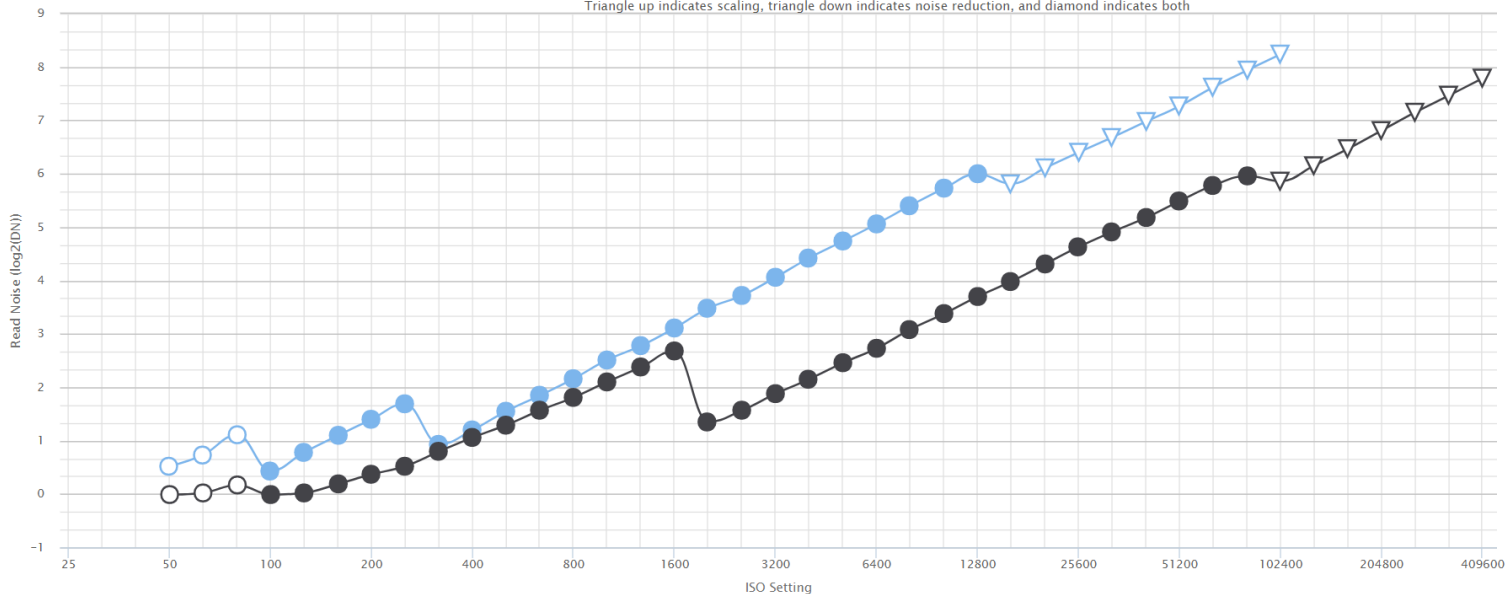
Megapixels vs Pixel Size

For astrophotography, larger sensor pixel size is better, resulting in lower noise. Consequently, while both have the same size sensor, the **12mp A7Sii** has much lower noise than the **61mp A7Riv**, particularly at higher ISOs.

	<u>A7R iv</u>	<u>A7S ii</u>
Sensor size:	Full frame 35.7 x 23.8 cm	Full frame 35.6 x 23.8 cm
Megapixels:	61 mp 9,504 x 6,336	12 mp 4,240 x 2,832
Pixel size:	3.76 μ	8.40 μ

Read Noise in DNs versus ISO Setting

Open symbols indicate values outside the normal analog range
Triangle up indicates scaling, triangle down indicates noise reduction, and diamond indicates both



Other Resources

- www.lonelyspec.com
 - Outstanding practical advice
 - Equipment guides, lens recommendations
 - Post processing tutorials
- FaceBook groups
 - <https://www.facebook.com/groups/theArtOfNightPhotographyGroup/>
 - <https://www.facebook.com/groups/StarAdventurer/>
- Light pollution maps:
 - <https://www.darksky.org/our-work/conservation/idsp/finder/>
 - <https://darksitefinder.com/maps/world.html>
 - <https://www.darksky.com/nightSkyBrightness>
- Star tracker reviews (for DSLR/mirrorless cameras only):
 - <https://nineplanets.org/guide/best-star-tracker-for-dslr/>
 - <https://nightskypix.com/best-star-tracker-for-dslr/>
 - <https://astrobackyard.com/star-tracker-astrophotography/>
 - <https://www.digitalcameraworld.com/buying-guides/best-star-tracker>

Best Astro Photography Lenses

Astro Lens Recommendations and Resources:

- <https://www.lonelyspeck.com/lonely-specks-ultimate-list-of-best-astrophotography-lenses/> great but it's a bit outdated
- <https://petapixel.com/2014/01/29/picking-great-lens-milky-way-photography/>
- <https://www.digitalcameraworld.com/buying-guides/best-lenses-for-astrophotography>
- https://www.astropix.com/html/i_astrop/lenses.html

Most common budget recommendation:

- **Rokinon / Samyang 14mm F/2.8**
- \$300-\$400, depending on the mount
- Widely available used in all mounts
- Pros: wide, low coma, cheap, fairly fast
- Cons: quality control, durability issues

Comparing Lenses for Nightscape Photography

The ratings on this chart take into account the physical amount of light that the lens can gather based on the area of the lens aperture, the field of view, and the max exposure time the lens field of view allows without producing star trails.

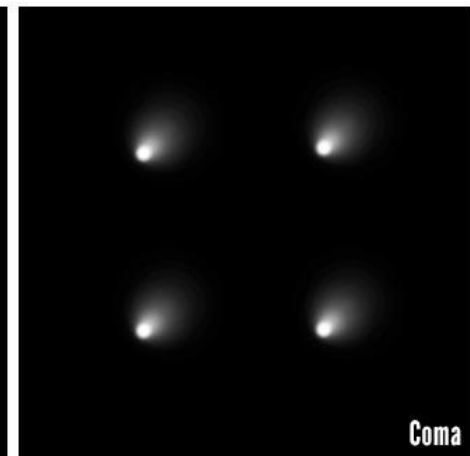
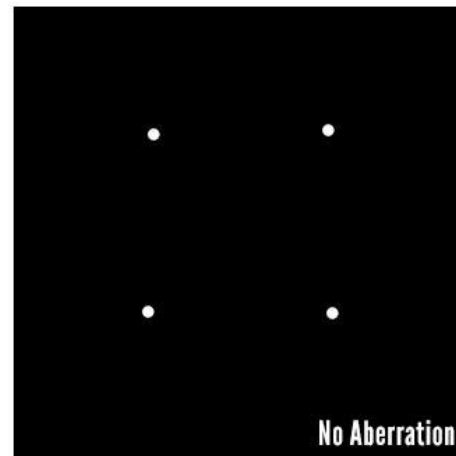
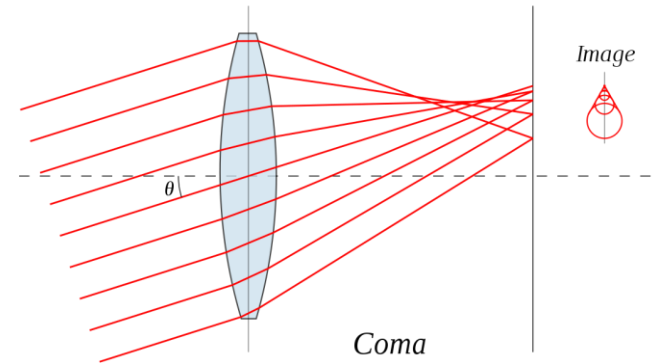
Untracked Astrophoto Rating = (Aperture Area) x (Angular Area) x (Max Exposure Time)

Lens	Clear Aperture Diameter (mm)	Aperture Area (mm ²)	Angular Area (radians ²)	Maximum Exposure Time (seconds) = 500/Focal Length	Untracked Astrophoto Rating
8mm/2.8	2.9	6	3.09	63	1,237
14mm/2.8	5.0	20	1.47	36	1,032
18mm/3.5	5.1	21	0.98	28	568
18mm/2.0	9.0	64	0.98	28	1,738
20mm/2.8	7.1	40	0.82	25	824
20mm/1.8	11.1	97	0.82	25	1,994
24mm/2.8	8.6	58	0.60	21	717
24mm/2.0	12.0	113	0.60	21	1,406
24mm/1.4	17.1	231	0.60	21	2,869
28mm/2.8	10.0	79	0.45	18	632
28mm/1.8	15.6	190	0.45	18	1,530
35mm/2.8	12.5	123	0.30	14	520
35mm/2.0	17.5	241	0.30	14	1,020
35mm/1.4	25.0	491	0.30	14	2,082
40mm/2.8	14.3	160	0.23	13	461
50mm/2.0	25.0	491	0.15	10	734
50mm/1.4	35.7	1,002	0.15	10	1,497

Table: <https://petapixel.com/2014/01/29/picking-great-lens-milky-way-photography/>

Lens Aberrations

Comatic aberration or “**coma**” distortion results in smeared star images. This characteristic is a primary consideration for astro lenses.

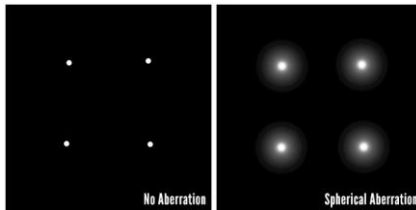


Other Lens Aberrations

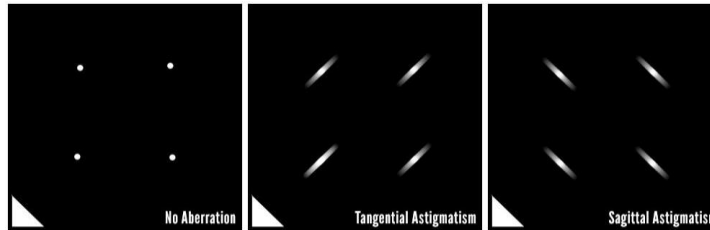
Chromatic aberration
causes purple or green fringing



Spherical aberration
causes fuzziness



Tangential and Sagittal astigmatism
cause stars to appear as lines



Other problems
Include:

- Distortion,
- field curvature
- Flare
- Vignetting



Advanced Stacking - Calibration Frames

Bias Frames

- Your camera inherently has a base level of read out noise as it reads the values of each pixel of the sensor, called bias. When averaged out, basically it's an inherent gradient to the sensor. BIAS frames are meant to capture this so it can be removed.
- Make sure it's dark (or put your camera in a box, etc), and put the lens cap on. Set your camera to the shortest exposure time possible. Take a bunch of pictures. Stack those.

Dark Frames

- When taking a long exposure, the chip will introduce "thermal" noise. Its level is magnified by three things – temperature, exposure time, and ISO. Dark frames are used to subtract this sensor noise from your image, and mitigate "hot or cold" pixels. (Some modern sensors automatically calculate dark levels and don't need dark frames). Dark Frames also will calibrate the chip so all pixels give the same value when not exposed to light.
- As above, darks are temperature and exposure time dependent, as well as ISO. You want your camera in the dark, with the cap on. To match the temperature, it's easiest to simply have your camera outside when the ambient temp is the same as when you image. (either do these after you're done for the night, or on another night the temp is the same) Set the exposure time to match your lights. Take a bunch of images.

Source: <https://practicalastrophotography.com/a-brief-guide-to-calibration-frames/>

Advanced Stacking - Calibration Frames

Flat Frames

- Flat frames allow you to calculate the correction factor for each pixel so they all give the same value when exposed to the same quantity of light for a given optical path. Things like dust motes, lens vignetting consistently reduce the light to a given pixel, flat frames allow you to mathematically remove them to give a smooth evenly illuminated image.
- There are lots of ways to do flat frames. One way is to put a white t-shirt over the end of the scope, and point it at a laptop screen. On a DSLR the exposure time should be so your histogram is between 1/2 and 2/3 on the back of the camera. Once you have it right, take a bunch. Since you're trying to capture how the dust, etc. was, this should be done right after you're done imaging for the night. You don't want your focus, rotation, etc. to change before you get your flats since doing so will change your optical path to each pixel.

Dark Flat Frames

- These are just like dark frames for your lights, but are for your flats. (May not be needed depending on what software & process you're using)
- Since these will be short to match your flats, they're quick. Just pop the lens cap on when you're done with your flats, and take a bunch of darks at the same exposure time.

Source: <https://practicalastrophotography.com/a-brief-guide-to-calibration-frames/>

Advanced Stacking - How Many Calibration Frames?

- Noise changes by the inverse square law. Going from 1 exposure to 2 exposures will reduce the noise by a factor of $\frac{1}{2}$, going from 2 frames to 4 frames will again reduce it by a factor of $\frac{1}{2}$. Then you need to go to 8 frames, then 16, then 32, then 64 then 128, then 256. As you can see it gets out of hand quickly.
- Realistically:
 - Bias: 50-100. They're fast, and you can take them any time.
 - Darks: Depending on your exposure time, these can be a chore. At least 20, and up to 50. Though for really long exposures, as few as 5.
 - Flats: 25-50, but really see no improvement over 25.
 - Dark Flats: Match your number of flats.
- These quantities don't change at all based on your number of lights.

Source: <https://practicalastrophotography.com/a-brief-guide-to-calibration-frames/>



Tim White

414 lights x 30 secs = 207 minutes

131 darks x 30 secs = 207 minutes

Sony A7Riv, Sony 200-600 @ 374mm

Sky-Watcher Star Adventurer

F/7.1, ISO 3200





Will Godward

15 sec x 36 images
Panorama

Sony A7Siii, Sony 20mm 1.8G
F2.0 / ISO 6400



Leo Froes

10 images x 20 sec

Canon 6Da

(18mp, APS-C, no H α filter)

Tokina 16-28 f/2.8

F/2.8, ISO 6400