NIGHTFALL

ASTRONOMICAL SOCIETY OF SOUTHERN AFRICA

THE ASTROPHOTOGRAPHY OF YOLANDA COMBRINK

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THE ASTROPHOTOGRAPHY OF YOLANDA COMBRINK

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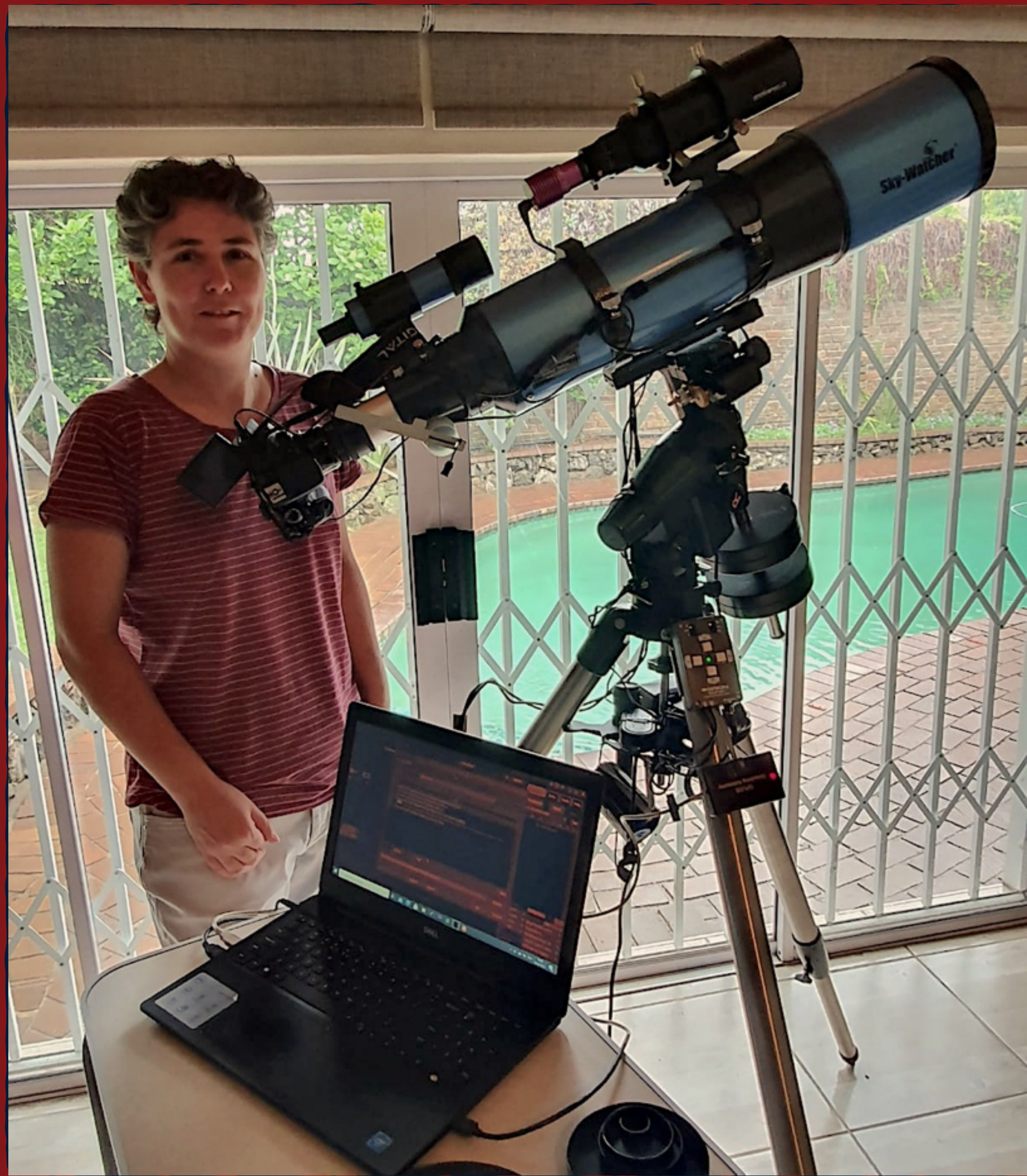
INTRODUCING

YOLANDA COMBRINK

In 1998 I attended the three-week Summer School at the South African Astronomical Observatory (SAAO) in Observatory, Cape Town. I was a postgraduate student at the physics department of the then Potchefstroom University at the time, working on my Master's Degree thesis, 'An Investigation into the Causes and Consequences of North-South Asymmetries in the Heliosphere'. The highlight of the visit was a week at Sutherland Observatory to assist a visiting astronomer with his observations. He played jazz music on his saxophone through the long nights. I couldn't sleep even if I wanted!

I learned how to operate the *SAAO 0.5m (20") reflector telescope*. This telescope was originally built by Boller and Chivens for the Republic Observatory in 1967, now known as the Johannesburg Observatory and defunct. Due to increased light pollution in Johannesburg it was moved to the Sutherland Observatory in 1972 upon the establishment of SAAO. This telescope was decommissioned in 2015 and donated to the Boyden Observatory located in Maselspoort in the Free State.



It was my first introduction into the complex interfaces that must be balanced between purpose-driven telescopes, cameras, and sky quality. It was all very informative, but living as a student trying to make ends meet I could not acquire a telescope of my own.

Shortly after receiving my M.Sc degree in Physics in May 2000, I found myself employed as a nuclear physicist at Eskom's head office performing safety studies for Koeberg Nuclear Power Station.

My odyssey into astrophotography began in October 2018 when I discovered the AstroBackyard YouTube channel produced by the Canadian astronomer Trevor Jones. Trevor produces high-quality astrophotography despite living under light polluted suburban skies in Ontario. His podcasts and YouTubes are treasures of how-to tips, resources, and advice. All of it is based on readily available amateur enthusiast equipment—an inspiration to anyone, and definitely me at the time.

Trevor's setup is straightforward and intuitive that anyone can emulate it. He mounted an ordinary DSLR camera to a refractor telescope driven by a traditional GEM go-to mount.

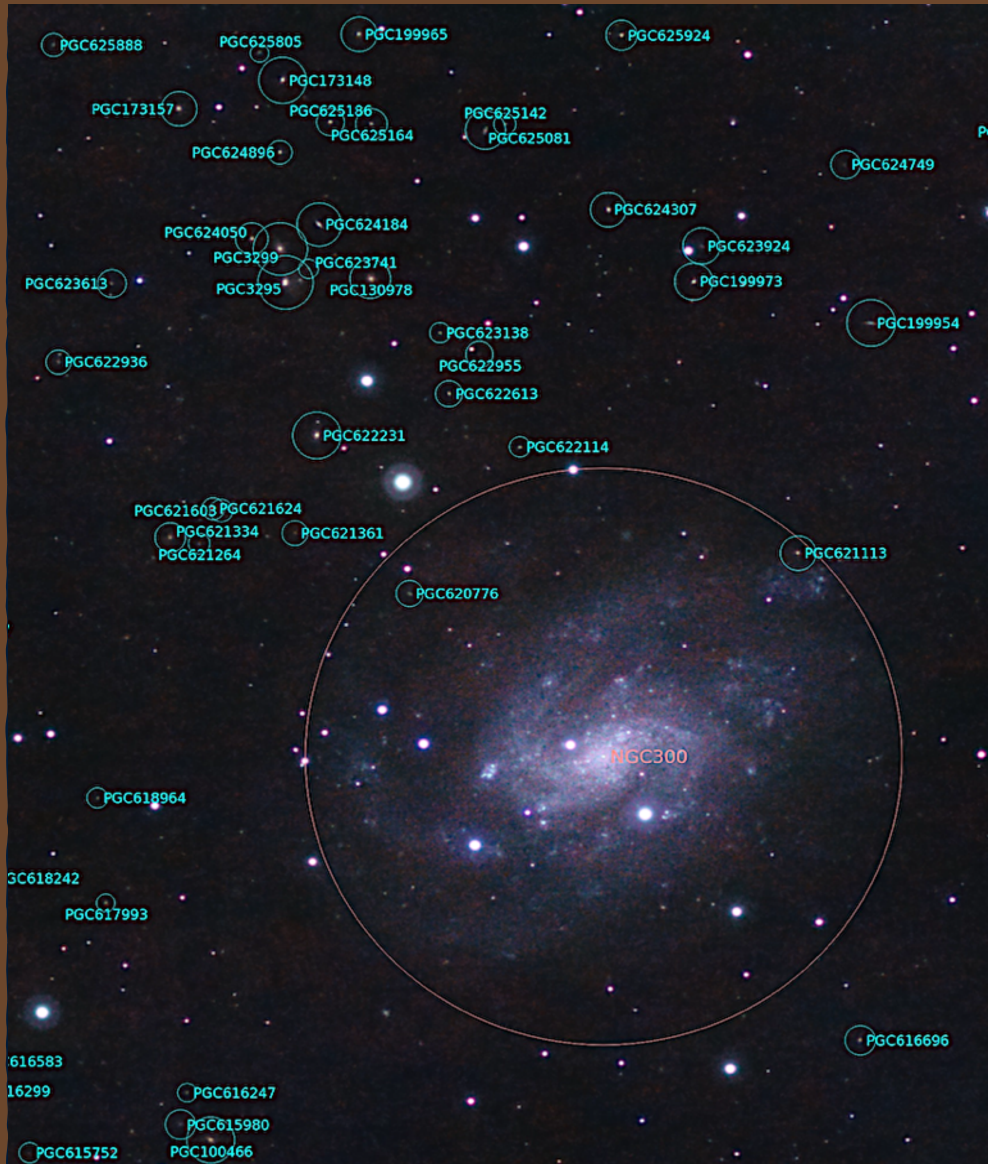
All of Trevor's equipment is familiar off-the-shelf brand-name gear that doesn't demolish budgets. He researched the best light-pollution (LP) filters to suppress the foggy hazes produced by the artificial light that plagues city-centre and suburban skies. I was so inspired by the quality of his images given his observing conditions that I soon switched my nocturnal lifestyle from sitting inside the home to standing under the skies. From the very beginning I was attracted to faint nebulae in the Milky Way.

I live in a light polluted Bortle 8 backyard. My home is in Edenvale, a small town on the East Rand in Gauteng. Given my dyspeptic skies, I took the early advice suggested to me and based my imaging methodology on maximising integration time. My logbook is filled with reports of total exposure times (integrated images) of 20 to 30 hours. It can take 2 to 3 weeks of all-night imaging sessions on 1 or more objects to come up with a single image like the examples in this article.

What looks on the page like a single image is actually hundreds of images, all stacked carefully and processed so they end up ad accurate representations of what exist in the sky. Integration times of 20 to 30 hours per object are assembled stacking hundreds of relatively brief individual exposures. Five hundred exposure frames (not counting bias, flats, and dark correction frames) are not unusual entries in my imaging logs.

In 2018 my only piece of equipment was a simple Canon DSLR. That actually turned out to be an opportunity. It gave me the liberty to pick and choose the best kit I could research to make best use of my camera. Learning what my kit should have was by no means an easy web romp through the commercial astronomy vendor web sites. I made a lot of mistakes and went through a lot of learning curves, but the end result was the exact right setup for my goals.

I've had my Canon EOS 650D / Rebel T4i since 2012. Last year I 'retired' it and now use it exclusively for astrophotography. I removed the Canon battery and replaced it with an external AC/DC adapter unit that draws power directly from an AC power source. Eliminating the heavy battery had the added virtue of reducing the swing inertia at the camera plane, which in turn translated to less image wobble on breezy nights.



As I eased my way into the vast literature of astronomy, the more I learned how related everything is. This imposing galaxy, NGC 300 in Sculptor, is something of a mirror image of the Milky Way. The Milky Way spans the entire sky. NGC 300 spans 29 x 13.5 arcminutes of it. Yet that same size of ellipse could accommodate 20 of the PGC Catalogue galaxies shown just above it. The PGCs are just one catalogue of many. The total number of galaxies in this image, down to magnitude 26 and 10 billion light years, could number into the thousands.

equipment

Telescope

Since I wanted to concentrate on faint, diffuse galaxies and nebulae, I leapfrogged the usual starter set of a 60 to 80 mm wide-field refractor. Instead, I went for the biggest glass I could afford, a *Sky-Watcher 150mm f/5* (750mm efl) two-element, air-spaced achromat. In the initial learning curve phase, I found that if I stopped the aperture down to 116mm (about f/6.5) the result was sharper pinpoints in the outer annulus of the image plane, with only minor, easily correctable vignetting.

Optical train

Refractors require a field flattener to correct for field curvature introduced by the spherical lens surfaces of an achromat doublet. A well designed field-curvature corrector produces uniformly pinpoint stars all across the frame. I chose a *Hotech 2-Self-C inch entering Adapter (SCA) non-reducing field flattener*. This model was designed for f/5 to f/8 refractors. Its lens cell has a standard M42 T-ring male thread on the camera side and a 2-inch (48mm) female filter thread on the telescope side. It attaches to the telescope via a 2-inch drawtube and requires a 55 mm back focus distance from the T-ring thread shoulder to the DSLR camera sensor.

The Hotech 2“ SCA field flattener is attached to the telescope drawtube by inserting it into the tube and turning the ring that causes expansion bands on the adapter to push outward, centering and solidly gripping the device in the drawtube. The device with the plastic cylinder and long tab are my ‘Five-Rand Feathertouch’ fine-focusing alternative to an expensive new focuser (details below).

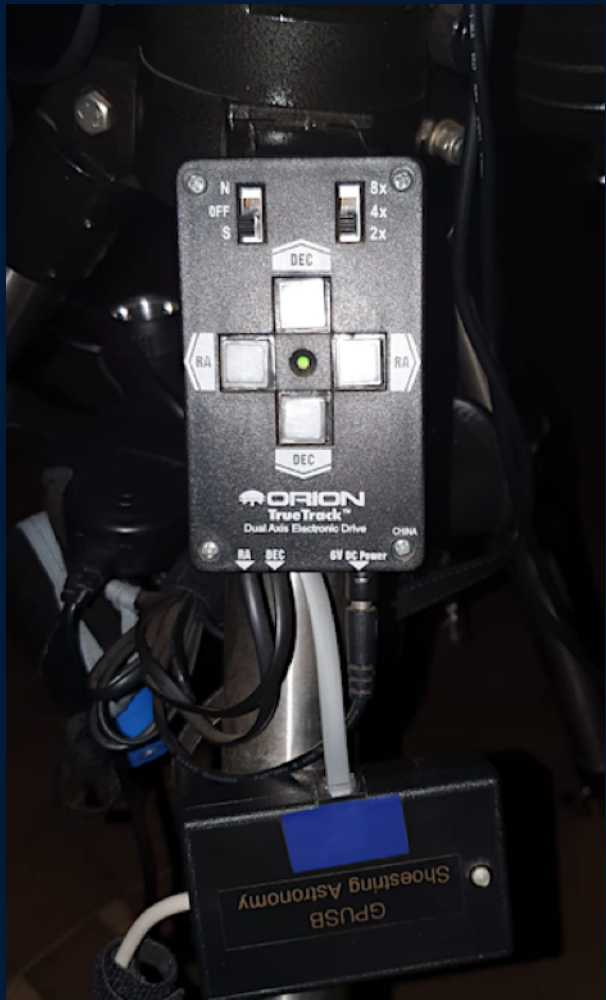
Visit Yolanda’s Flickr page here:

Telescope mount

A standard off-the-shelf *Sky-Watcher EQ5* mount came as a combo with the telescope. The EQ5 mount has a payload limit of 10 kg. I use the software *Astro Photography Tool* (APT) with the planetarium software *Stellarium*, which allows me to blind-solve my images and show me in Stellarium where my telescope is pointing and whether my target is framed well within my telescope's field of view

To enable image tracking at sidereal rate in right ascension and electronic control of declination, I added the *Orion TrueTrack dual axis motor drives* and a hand controller. The Orion TrueTrack motors require 6V DC power. For that I use four AA rechargeable batteries which I can swap out with another spare set during the night, if needed.

I added the *GPUSB EQMOD* from *Shoestring Astronomy* to the Orion hand controller to establish communication between my mount and laptop for auto-guiding.



Controller

Modifying my Orion TrueTrack hand controller required opening the hand controller and carefully soldering five wires to the keypad board in order to add a ST-4 autoguider port (the grey cable). The ST-4 port connects to the Shoestring Astronomy USB Guide Port Adapter, which in turn connects via a USB cable to my laptop thus establishing communication between my EQ5 mount and *PHD2* for auto-guiding.

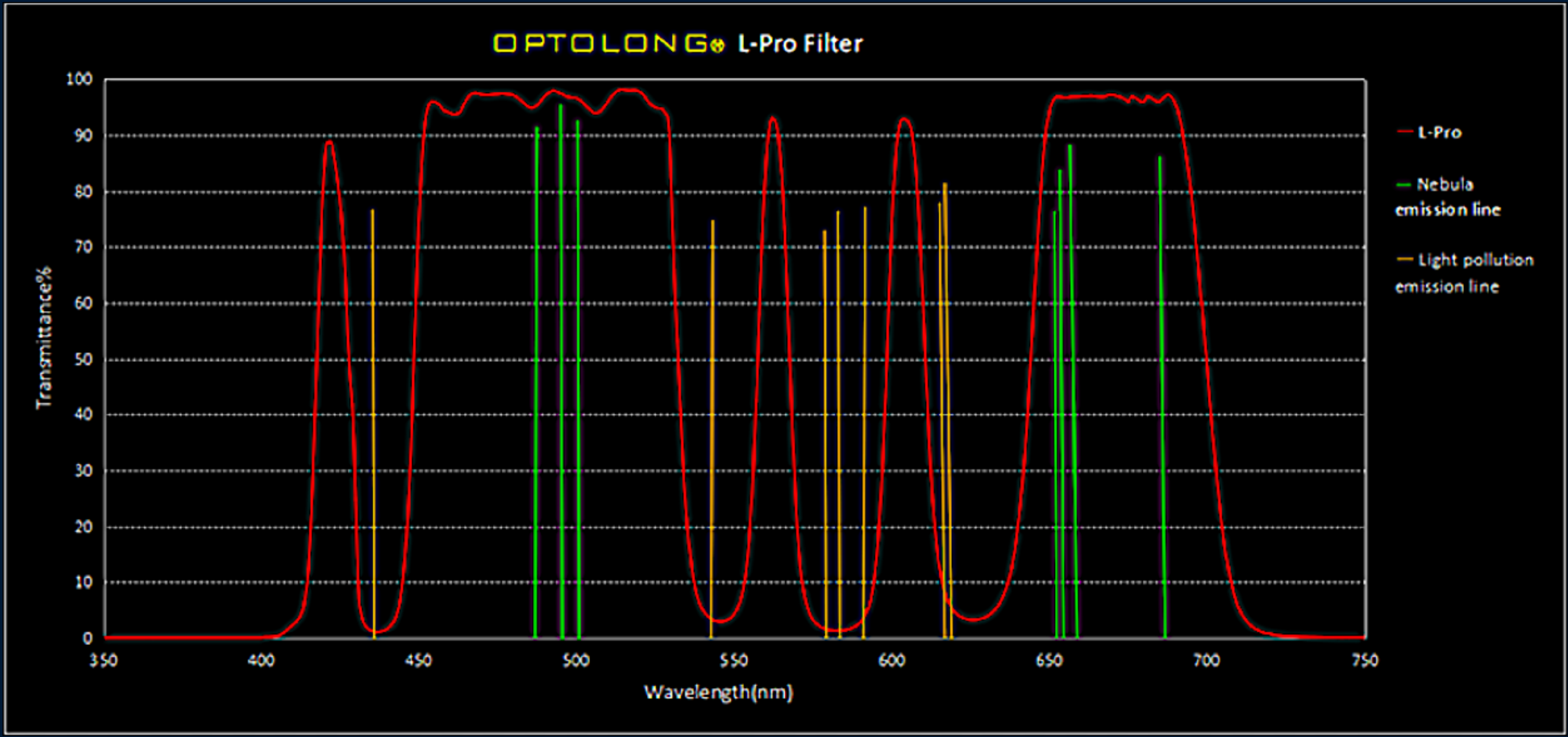
Guide scope and camera

I paired a *Starfield 60mm f/3.8 guide scope* with an *Altair Astro GPCAM2 290 mono camera*, connected to my laptop via a USB2.0 cable. I use the free software *PHD2* for auto-guiding.

Once I arrived at the stage when I was no long producing images filled with pretty little figure-8s, I tackled the astrophotography learning curve in earnest. The first hurdle to overcome was the learning the skies above me.

Filters

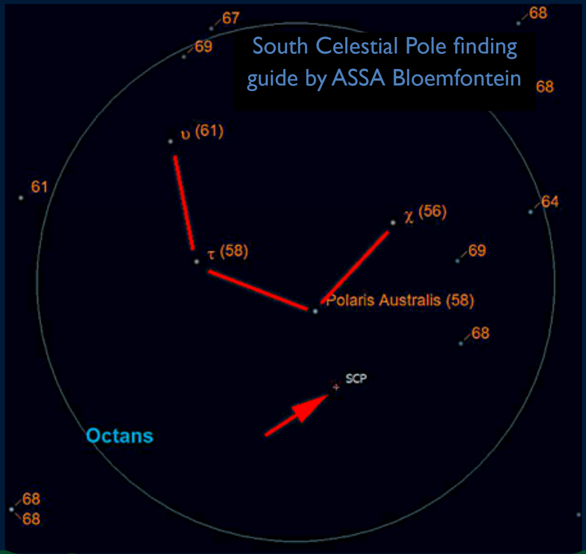
I chose an Optolong L-Pro 2″ multi-bandpass filter specifically designed for imaging broadband emission typical of galaxies and reflection nebulae in light-polluted skies. The filter suppresses the wavebands associated with mercury and sodium vapour lights, as well as the naturally occurring skyglow caused by neutral oxygen emission in our atmosphere (collectively called telluric contamination). At the same time, the Optolong L-Pro also maximises light throughput in the spectroscopically important emission lines OIII (495.7nm and 500.7 nm), Hydrogen-alpha (656nm), H-beta (486nm), NII (654nm and 658nm), and SII (672nm).



Reducing the amount of light pollution and skyglow that reaches the eye or camera chip produces a darker background sky. But the Optolong L-Pro is more than a simple contrast booster that is more appropriate for visual observation than imaging. When processing images, contrast is optimised by one of the correction algorithms in the imager's processing application—DeepSkyStacker and PixInsight in my system. The Optolong L-Pro optimises the throughput of OIII, H-beta, NII, H-alpha, and SII emission lines while suppressing shot noise (random noise) adjacent to these bands. The spectral lines are produced by various nuclear reactions in stars. The more single-line photons an image processor has to work with, the more accurate the rendering of the original object. Elevating throughput in a glass filter is achieved by coating the surface of the glass (Schott B260 in this case) with a one-atom thick layer of a molecular medium. The particular molecule chosen reduces the tendency of the filter's glass surface to reflect rather than transmit the desired wave band. In a multi-band filter like the Optolong L-Pro, each waveband enhancement requires a distinct molecular layer for that band alone. Manufacturing such a filter commercially translates to multiple separate ion deposition processes that layer many coatings one at a time on top of each other. The result is called dielectric, meaning that it transmits rather than absorbs signal strength. Additionally, the coatings must not interfere with the activities of all the other coatings on that piece of glass. That is why these filters are so expensive.

I have to thank my Mom and Dad for the rich contrasts in my images. Two years ago when they wanted to buy me a 'we-just-want-to-spoil-you' gift, I requested an anti light-pollution filter. It took a while to explain the rationale for my oddball gift request, but in all good humour I soon found myself opening the box that turned my bilious backyard skies into the only Karoo-class patch of sky in the East Rand.

polar alignment



Sharp focusing

Focusing is critically tight in short f/ratio telescopes. I use an Astromania Bahtinov focus mask, which I pair with the Bahtinov Aid tool in APT for manual focusing.

Five-Rand Feathertouch

To make the incremental adjustments needed for perfect focus with the Sky-Watcher stock rack-and-pinion focuser of my telescope, I crafted my own 'Five-Rand Feathertouch' focuser based on Dylan O'Donnell's YouTube video 'How to make a Feathertouch Focuser for 5 cents'.

The south celestial pole is unfortunately blocked from view at my observing location. The E-Z method of south polar alignment centring Sigma Octantis in a GEM polar-axis finder telescope is impossible. The arduous job of devising a polar alignment workaround was like running a marathon backward—frustrating and incremental, but eventually successful. I finally learned how to configure the Drift Align tool in PHD2 to dial in my polar alignment.

Since it is tedious to set up my gear, balance the telescope, and polar align when I'd rather spend that time catching photons, I've marked my observing spot with three dots for the tripod leg tips and keep my setup permanently assembled and covered inside the house. I've also marked my telescope's balanced position (both on the counterweight rod and the mounting plate's position on the mounting bracket) and can remove the main telescope with all attachments and carry it separately from the tripod with EQ5 mount and counterweights attached. The spot mark for my tripod legs and pre-balancing the telescope position puts my mount within a few arcminutes of Sigma Octantis every time.

Before starting an imaging session, I point my telescope to the celestial meridian and run the **Guiding Assistant tool** in PHD2. This gives me an indication of the seeing conditions and recommended settings for guiding parameters. It also gives an estimate of my polar alignment error. If the estimated polar alignment error after running for two minutes is more than 3 arcminutes, I stop the Guiding Assistant tool, adjust the location of the tripod legs relative to the three dots, and rerun the Guiding Assistant tool. With an alignment error that small, my exposures aren't long enough to magnify dot creep. Integrating the image in pre-processing effectively nulls them out.

image acquisition

I use the software *Astro Photography Tool* (APT) for image acquisition. At the heart of high-quality astro-imaging today is the process of *image stacking*, which maximises the total amount of photon energy deposited on a pixel while minimising the total amount of noise. Image stacking is also known as *integration*, and is based on the *'law of large numbers*'.

Image integration

Integration averages the photon count value of each image pixel across many images in order to approximate the actual numerical photon count for each pixel. The photon count value of the signal from the object adds up to be slightly more than the photon count of pixels representing the dark sky (called background shot noise). The sum of each value on every pixel averages in favour of signal over noise. Stacking more light frames increases the signal-to-noise ratio (SNR) and adds to the total integration time in seconds and minutes. In a location with light-polluted night skies typical of cities and suburbs, stacking reveals the signal from faint nebulosity only if the faint signal is already there to start with. The question that an astro-imager faces when scheduling a night's image sequence in the automated software becomes, 'How much signal do I need to render noise negligible?'

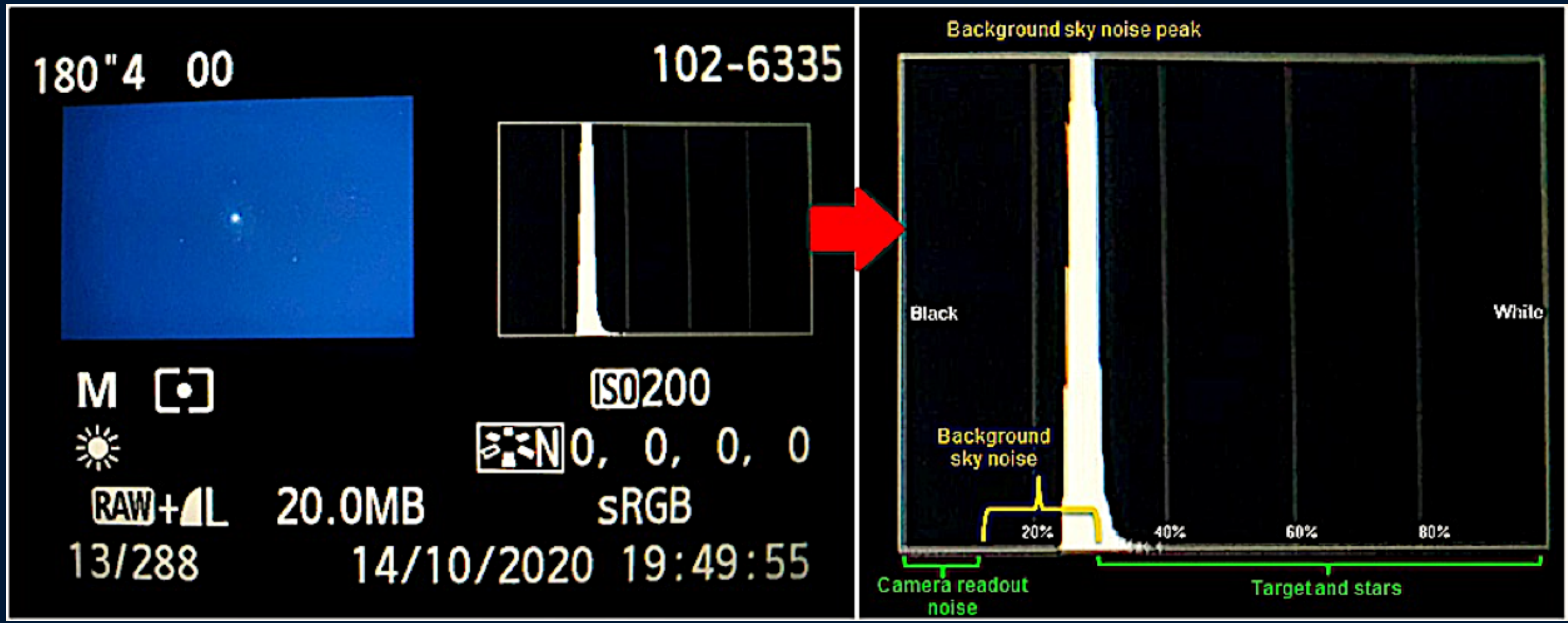
The answer has to take into consideration the f/ratio of the telescope (i.e. how 'fast' it is), the sensitivity of the camera; the overall luminance and contrast of the object (bright or faint), and the night's sky conditions—how 'dark' the sky is, the presence of dust, humidity, invisible high-altitude clouds, and even the glow of airborne humidity and dust, and nearby sports matches being played outside under floodlights. Some of these factors can be quantified; others change hour by hour. Hence the need to calculate a total exposure time long enough to tease the faint signal out of the background noise — but not too long so I don't waste hours of imaging time trying to turn very good into slightly better.

For me the best method to improve SNR is to compile many, many image frames—which is why my imaging logs consistently report 300 to 600 individual exposures and 20 to 30 hour total integration times.

It can take several *weeks* to compile enough individual frames to render a high-quality image that looks to the reader like seeing the object at Sutherland. The term 'set and forget' has real meaning for imagers like me who are obliged by their skies to take lots of pictures.

It is important to remember that the signal-to-noise ratio (SNR) from stacking does not go up in tandem when increasing the number of exposures. Instead, the number of exposures increases the signal faster than the noise. Increasing the SNR does not reduce noise; it makes noise less apparent.

These days an amateur enthusiast with a four-inch scope can produce images that would have been the envy of the Palomar 200-inch some four decades ago. Photographic film records only about 7% of the incoming light. Photographs using emulsion coated on glass plates raised this to between 10% and 12%. The earliest charge-coupled detectors (CCDs) raised the capture rate to 70%. Today's more advanced active-pixel (CMOS) sensors detectors achieve capture rates as high as 90%. The arrival of CCD imaging and megapixel imaging chips opened the floodgates to the astronomical Golden Age we presently live in.



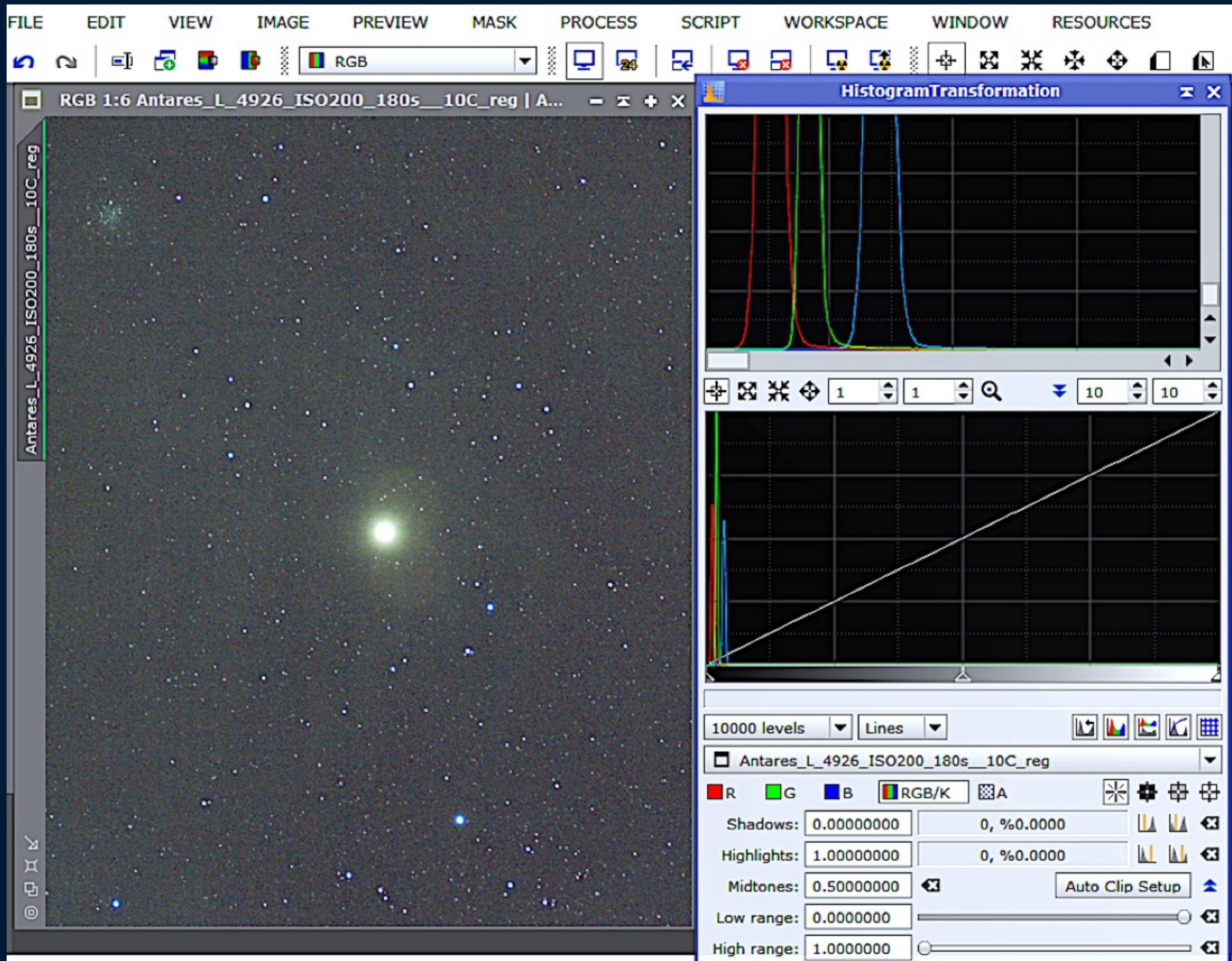
A useful tool for understanding how to accurately expose your images is to look at the histogram of your image on the LCD screen on the back of the DSLR camera. The histogram is a bar graph that displays how many pixels are at a particular brightness. The darkest pixels (i.e. shadows) are on the far left side of the graph and the brightest pixels (i.e. highlights) are on the far right side. Since noise in an image lives down in the darkest pixels of an image, it is located at the extreme left of the histogram. Most of the pixels in a typical astro photo will be of the *background sky noise* itself represented by the 'mountain' and peak of the histogram appearing somewhere at the left side of the histogram. As you move towards the right and along the flat tail running off towards the right-hand side of the histogram peak, more and more of the pixels will be from the nebulosity, galaxy arms and other faint, fuzzy objects present in the image.

There is no hard 'line' where the background sky stops and the 'interesting stuff' starts. The most useful information will usually appear in the very right-hand side of the peak and the first part of the tail. This makes it hard to tease out the fine detail in a deep sky image.

dealing with light pollution

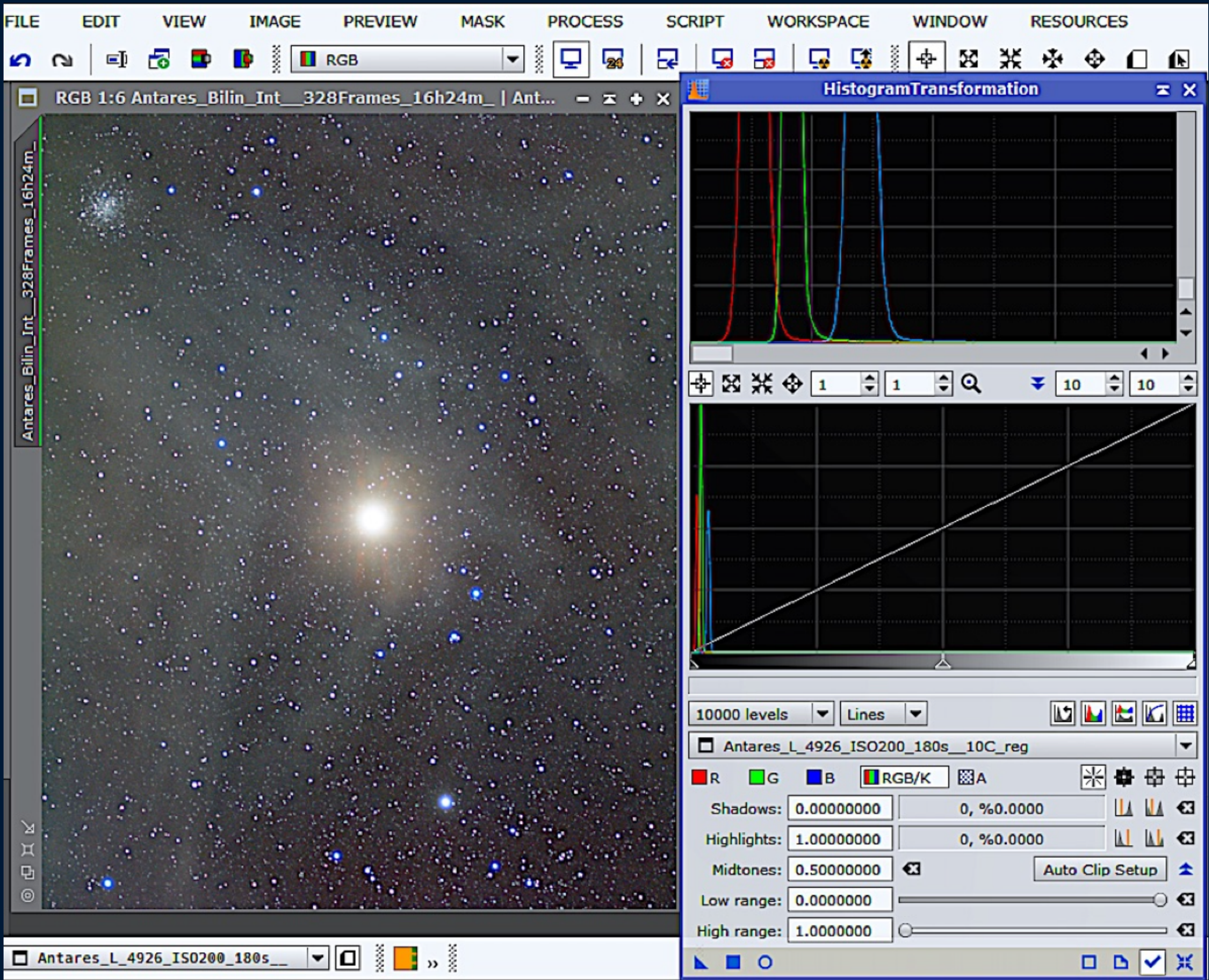
When you are imaging under very light polluted skies, the exposure length per light frame doesn't matter much because the *readout noise* of the camera is easily swamped by the background sky noise. Stacking will only reveal the signal from the faint nebulosity if the faint signal is already present in the individual exposures. Thus, to get the best results you need to expose long enough to get the faint signal out of the background sky noise of your histogram, i.e. you want to move your image data away from the left-hand side of the histogram.

You do not want to have the peak of your histogram all the way to the right because you're likely to clip the highlights (i.e. star cores) to pure white. If this happens, lower your ISO first to gain a better *dynamic range*. If this is not enough, reduce your exposure time. A good and simple rule of thumb is to *expose to the left* where the idea is to expose long enough to get the histogram peak at about the 1/4 to 1/3 brightness level (i.e. 25% to 33%) on the camera LCD screen. When you expose to the left, you are preserving all shadow detail and allowing the camera to pick up as many highlights as possible.



ABOVE: This screen shot of PixInsight shows what can be seen in a single 3-minute exposure, calibrated, and registered light frame of Antares. The corresponding histograms of the red, green, and blue (RGB) channels are overlaid on top of each other. The graph at the top shows the RGB histograms zoomed in by a factor of 10. Since the light frame consists mainly of darker pixels the RGB histograms are concentrated on the left-hand side, but still well separated from the left-hand edge, of the histogram.

Below: Screen shot of PixInsight showing the results of what can be seen in 328 stacked 3 minute exposure light frames of Antares (unprocessed). Also shown is the corresponding histograms of the RGB channels overlaid on top of each other. The top graph shows the RGB histograms zoomed in by a factor of 10. This stacked, unprocessed image of Antares shows how *integrating more images increases the SNR and reveals more of the fainter nebulosity present around Antares.* Since the image has not been stretched, it still consists mainly of darker pixels and the RGB histograms are concentrated on the left-hand side, but still well separated from the left-hand edge, of the histogram.



Dithering is a technique that suppresses pixel error by shifting the telescope pointing direction very slightly in between exposures, typically by a few arcminutes in random directions. This in turn shifts the position of the object in the image on the camera sensor by a few pixels. The process nulls out the unwanted shot noise of hot and cold pixels, cosmic ray artefacts, and pattern noise from the camera's own sensor.

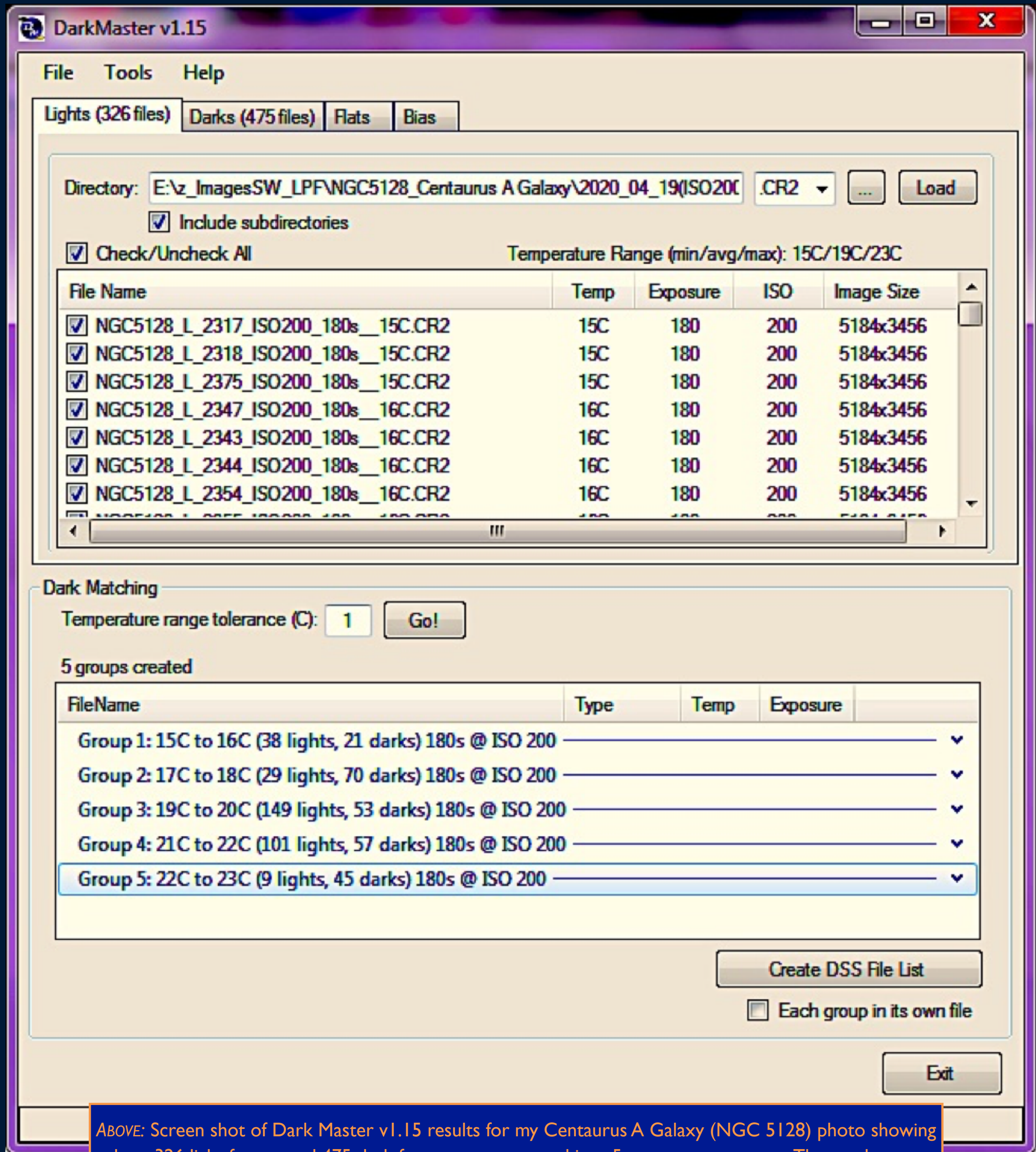
Dithering is crucial when using an uncooled DSLR camera like mine, because it averages out the camera's own thermal noise (called dark current noise).

Satellite trails appear in many images in an integration stack these days. A typical light trail occupies a single frame. Integrating over several hundred images during image stacking nulls out frames that contain obtrusive data. Unwanted streaks are effectively swamped till they are irrelevant. My *DeepSkyStacker (DSS)* software does such a good job of suppressing streaks that readers will never suspect that a streaky frame lurks in there.

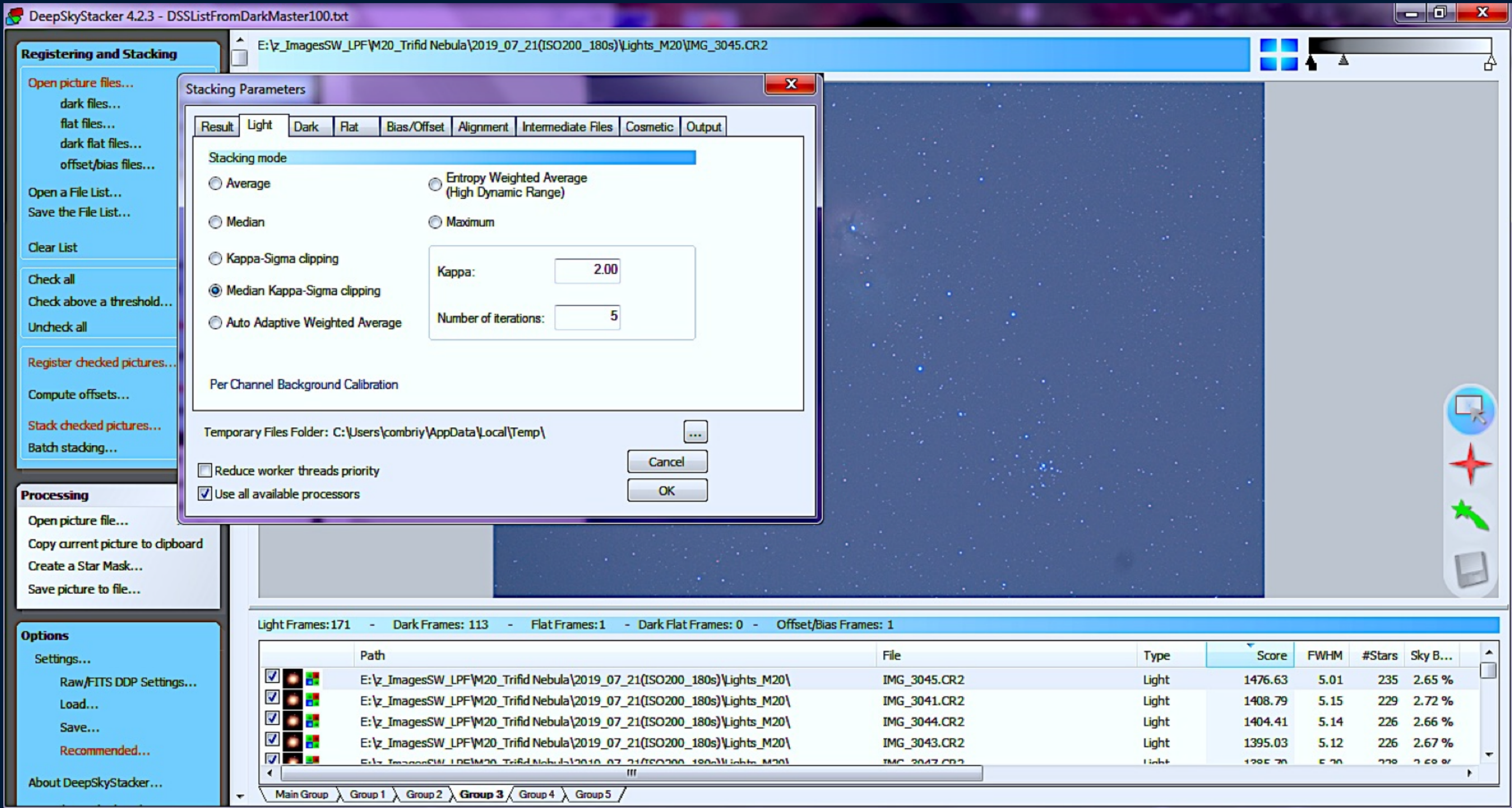
processing

I use the free software Dark Master v1.15 to organise my light and dark frames into groups based on temperature. I then use the free software DeepSkyStacker (DSS) to calibrate and stack all my images and PixInsight for further processing. Although PixInsight can also do calibration and stacking, I prefer DSS mainly because it is quick and easy and the difference in stacked image results seems insignificant. PixInsight is expensive to buy and in the beginning demands a lot of attention to understand, but once you develop a processing workflow that works for you, there are no limits as to what you can do with it.

Capturing image frames and calibration frames (dark, bias, flat, and dark flat frames) for an astro photo is only half of the hobby. The other half consists of processing astrophotography data and can be equally challenging. I still spend many hours watching tutorials and reading tips. The seemingly commonplace images shown on these pages compress several nights of image capture and several more of processing (and re-processing!) before I was satisfied with it.



Above: Screen shot of Dark Master v1.15 results for my Centaurus A Galaxy (NGC 5128) photo showing how 326 light frames and 475 dark frames were grouped into 5 temperature groups. The results was saved as a DSS File List which is a text file in a format that can be opened directly in DeepSkyStacker.



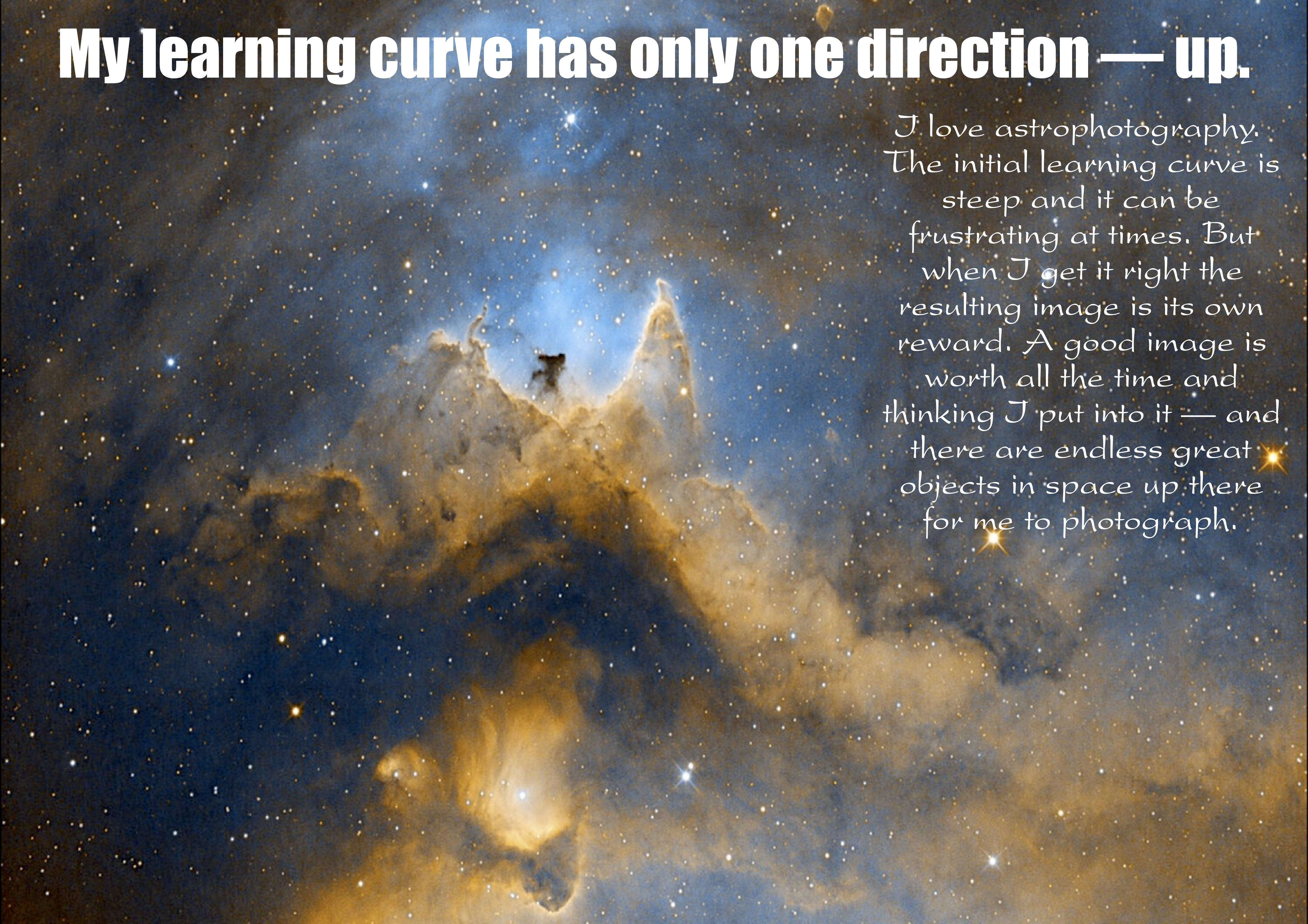
ABOVE: Screen shot of DeepSkyStacker showing the selection of the *Median Kappa-Sigma clipping mode* which is recommended for stacking a large number of light frames. Median Kappa-Sigma clipping is an iterative rejection algorithm where for each iteration, the mean and standard deviation (Sigma) of the pixels in the stack are computed. Each pixel which has a value from the mean that is higher or lower than Kappa × Sigma is replaced with the median value, while the mean of the remaining pixels in the stack is computed for other pixels. This stacking mode is very efficient in removing all traces of satellite and airplane trails.

tips & tricks

Choosing new objects to image used to be a matter of trying my hand at familiar favourites like M8 the Lagoon Nebula or M16 the Eagle Nebula as obligatory steps up the astro-imaging learning curve. If an image of M17 the Swan Nebula turns out to be less accurate or eye-catching as other images, then where did I go wrong? Did I miscalculate the total acquisition time I needed? Did I under- or over-correct a given variable in the processing phase?

Besides mastering aspects like balancing your telescope, polar alignment and cable management, using a light suppression or narrow band filter, dithering and stacking many light frames, the following also contributes to capturing good quality astro photos:

- Work out where the best place in your backyard is to both shield your equipment from stray light and get the best view of objects in the night sky.
- Stray light reduces as the night goes on. You'll probably find that after midnight the amount of stray light seems to be less than earlier in the evening.
- The higher your object in the sky, the better and darker your sky conditions will be. Image your desired object when it is highest (on either side of the meridian line) in the night sky.
- Moonlight is nature's own light pollution. Thus, when the moon is out plan on imaging bright targets located away from the moon. Since I don't have any narrow band filters, I try not to image when the moon is illuminated more than 30 – 40%.
- Learn to take good calibration frames, especially flat frames used to correct vignetting, gradients and dust present in your imaging train.
- Turn off long exposure noise reduction in your DSLR camera. It will cause each exposure to take twice as long when it's turned on and also means you'll be double-processing your images, causing a reduction in image quality.
- Shoot in RAW – it gives you way more information to work with than JPEG and really allows you to do a lot more in post-processing.
- To record higher contrast and finer details, be ruthless and reject the worst or bad light frames before and/or during stacking.



My learning curve has only one direction — up.

I love astrophotography. The initial learning curve is steep and it can be frustrating at times. But when I get it right the resulting image is its own reward. A good image is worth all the time and thinking I put into it — and there are endless great objects in space up there for me to photograph.

The astrophysics behind Yolanda Combrink's images

Dana De Zoysa

A great many astronomy enthusiasts have moved from visual observing to making permanent records of the objects they fancy. The sheer number of images inevitably results in too many fine images getting a cursory glance without much further thought.

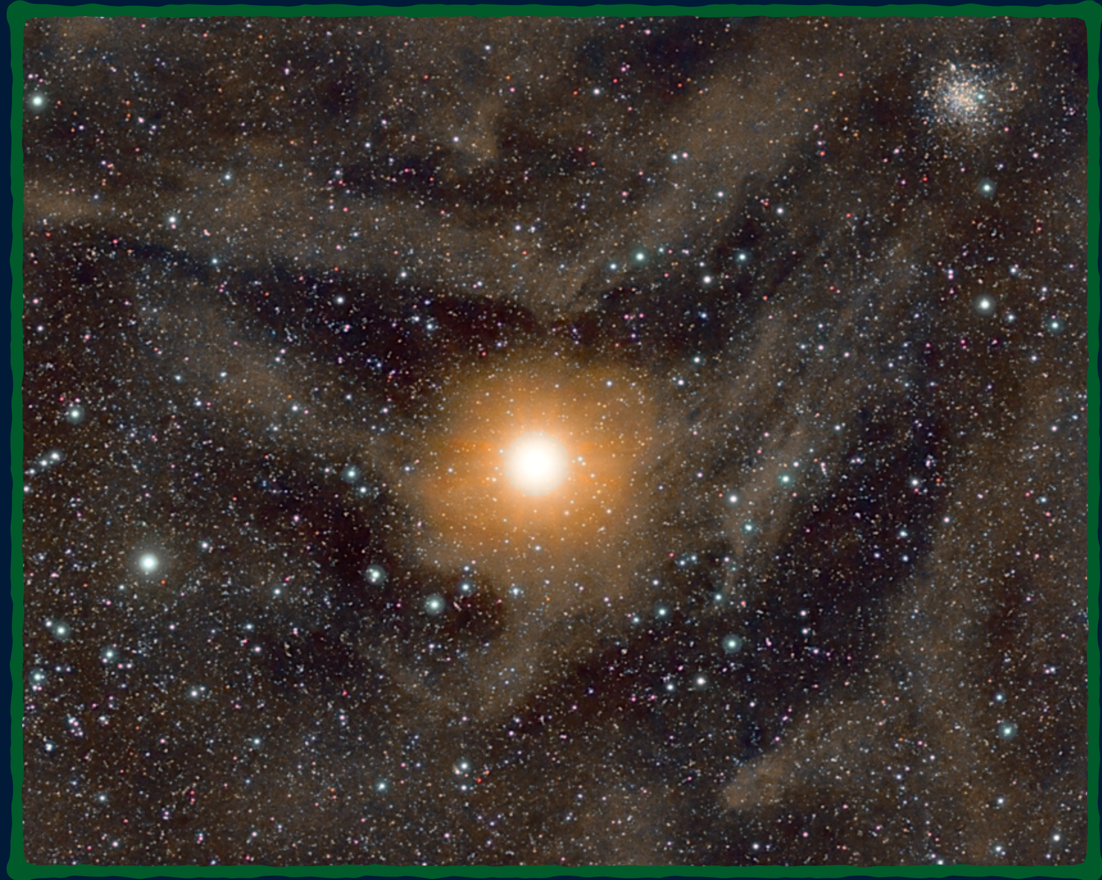
Let's take another approach: Assume that Yolanda Combrink's images are records of astrophysical fact that deserves our attention.

What happens if we take the early efforts of an astrophotographer like Yolanda and give them to the same thoughtful scrutiny that we would give to the latest Gigapixel Glory from Mauna Kea, Roque de las Muchachos, or Cerro Tololo?

What, indeed, are the stories Yolanda's pictures tell?

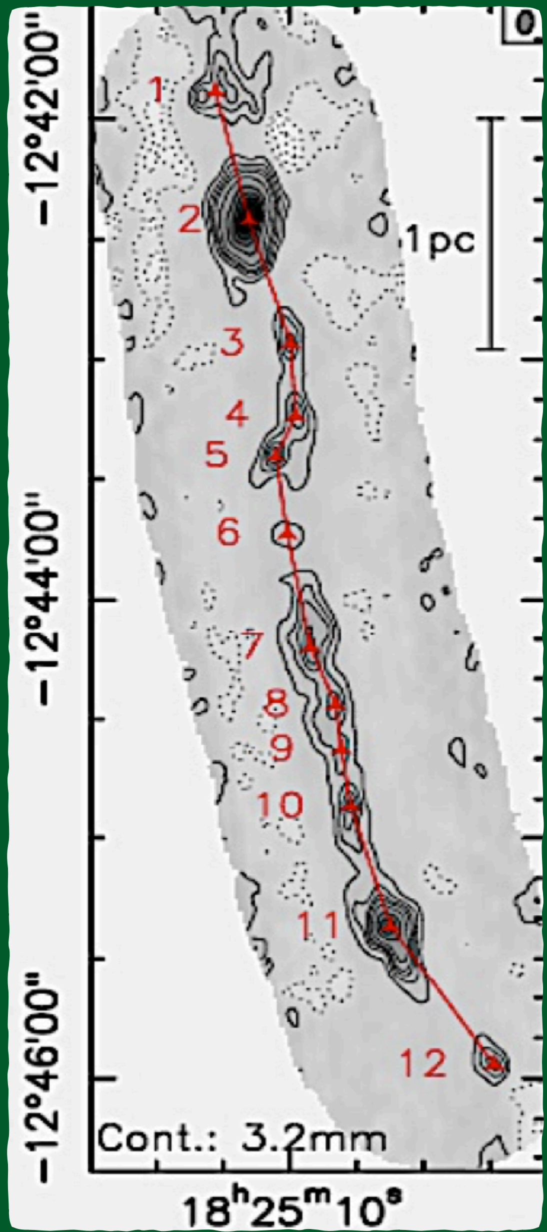
Let's find out!

antares



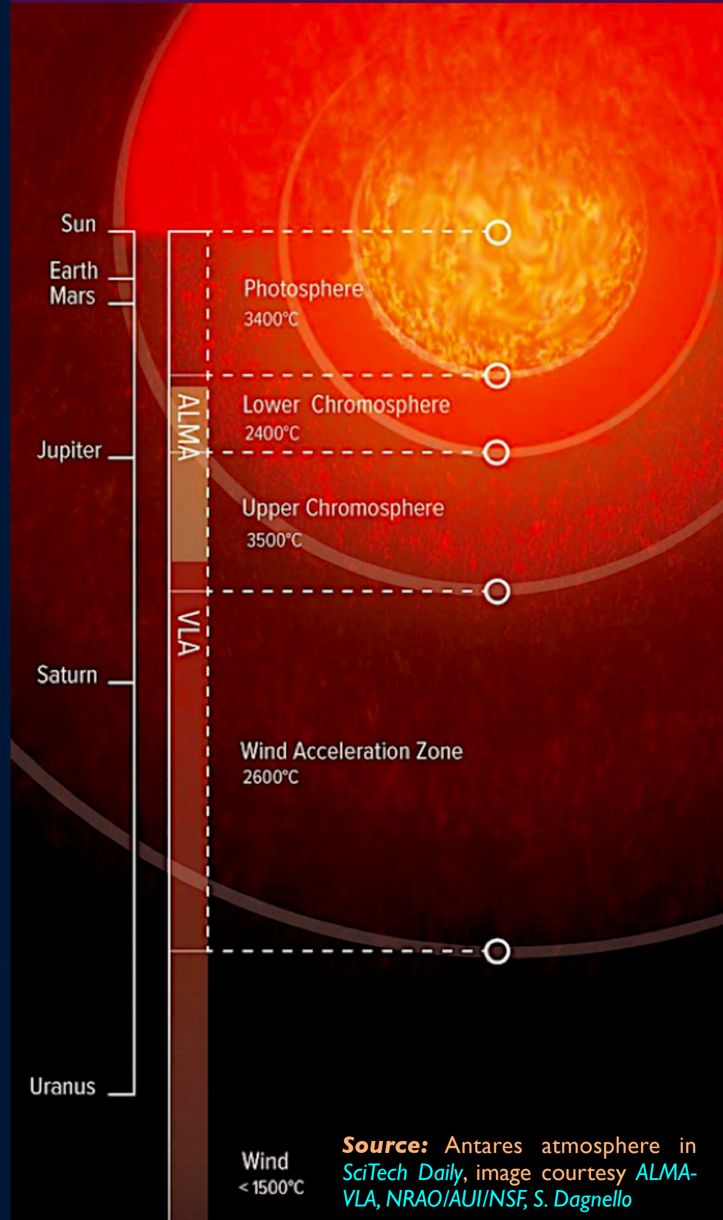
Which of these two images of the star field around Antares (α Scorpii) and the distant, reddened globular cluster NGC 6144 is the more informative? The image on the left adopts the traditional exposure philosophy which emphasises the rich density of hydrogen alpha emission from the knotted wraiths of star-forming gas in the field. Little of this nebulosity is directly associated with Antares itself, which lies about 170 pc (550 ly) from the Sun, while the filament-like emission lies beyond it. Antares' intense radiation fluoresces the cool hydrogen gas behind it, which is why it is reddish instead of the blue tinge of cold dust in reflection nebulae. The problem with the left-hand image is that the ionised Hα emission behind it does not lie in amorphous sheets but rather in filamentary 'ropes' which are actually magnetic solenoids that compress electron flow into the centres as the gas flows from one end toward the other (usually to the right, according to the familiar '*Fleming's right-hand rule*'). Yolanda's image above stacked just enough photons to highlight the twisty strands of magnetic flux tubes, while also suppressing the distracting number of unrelated field stars. The result is less dramatic but more informative science.

High-mass stars such as Antares do not generally begin in the familiar round balls of stars associated with the 'collect-and-collapse' scenario of cluster formation. Instead, massive stars tend to begin their lives as strings of overdensities in magnetically aligned solenoids, or flux tubes like this example from *Beuther 2015*, Fig. 2. Within a few hundred thousand years the magnetic fields weaken due to the effects of simple diffusion (electrons bleeding away slowly) and the more divisive forces of supersonic shock turbulence from protostellar jets and the intense gas winds driven from the surfaces of giant stars. Shock waves and high-velocity jets from protostar accretion discs do more than destroy magnetic confinement, however. They also form compression surfaces along which low-mass gas pockets can collapse into stars. The large populations of low-mass stars in clusters form in this way. Many are binaries and trinaries whose orbital interactions can often hurl the smallest stars completely out of the forming region. Some of the low mass stars indeed escape, but most simply fall back into the melée of a young cluster, where they usually mass-segregate toward the outer regions. See *Federrath 2015* for a more complete explanation. Watch Chris Federrath's astonishing *video simulation on YouTube*.



Hidden deep inside the faint linear structures in Yolanda's Antares image are linear strings of clotty isopleths which reveal very young massive stars in the early gravitational free-fall stage. They are fed massive amounts of raw gas via the magnetic confinement and free flow of gas along their natal flux tubes.

Antares is a 12 million year old red supergiant of between 11 and 14.3 solar masses. It is in an evolutionary phase in which it hurls off prodigious amounts of envelope gas (see *this video*). Pinning down the envelope structure on star like this is difficult because spectral lines are being generated at different depths in the atmosphere. Different wavebands emanating from specific emission layers produce different results depending on the wavelength observed. That enable the ALMA and Very Large Array telescope teams to put together this map of Antares' emission layers.



Source: Antares atmosphere in *SciTech Daily*, image courtesy *ALMA-VLA, NRAO/AUI/NSF, S. Dagnello*

ρ ophiuchi

The *ρ* or rho Ophiuchi region is one of the most-imaged patches of the sky. With old stars, young stars, multiple stars, dark clotted nebulae, and brightly coloured red emission and blue reflection nebulae, a budding imager has a huge salad bar to choose from.

Here Yolanda directs our attention to the quiescent, faint reflection nebulae surrounding the quadruple B-type star system *ρ* Oph. As with the Antares image earlier, a restrained approach to image compilation results in a work that is more scientifically satisfying than visually spectacular.

The nebulosity surrounding *ρ* Oph has the cyan-blue hue of light from a bright star reflecting off masses of dust. Galactic gas typically hosts 1 dust particle per 1000 to 10,000 gas particles. A multi-band check of images from X-ray to micron shows the *ρ* Oph region to be quiescent in infrared and Hα emission, but bright in 3.2 micron emission from cold dust in the 20 to 30 K range. Most of it would be carbon-based.

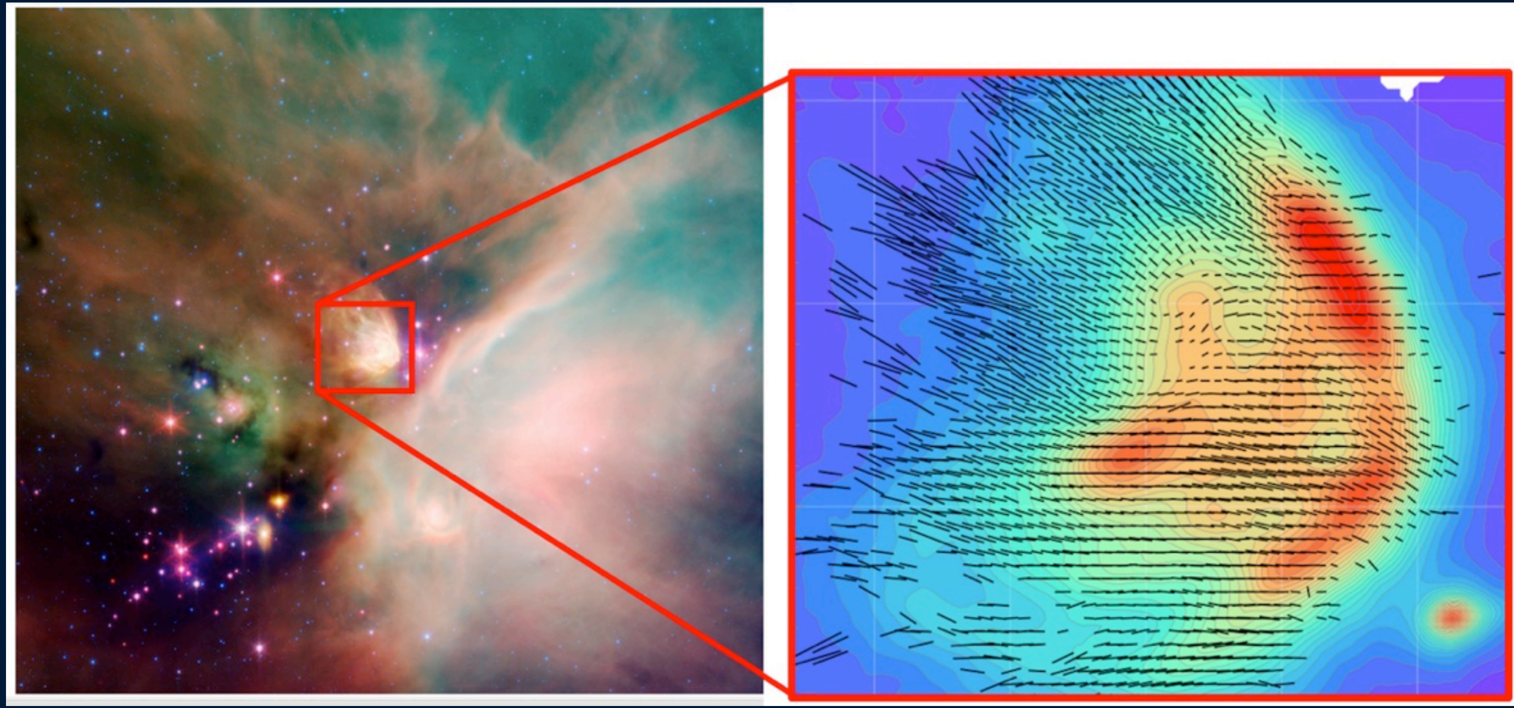
The clouds in Yolanda's image suggest a wave-like pattern of peaks and troughs.

Captured over several nights in June and July 2020. 608 x 3 min light frames at ISO200 with dark, bias, flat and dark flat frames. Total integration time 30h 24m.

Larger-scale images suggest the same. The most common explanations for broad, linear waves in quiescent cold gas are magnetic flow along compressed field lines (solenoid structures), and/or compression peaks and troughs from passing large-scale but slow-moving shock waves. ‘Slow’ in these instances mean from Mach 1 to 2.

Around 5 to 3.5 million years ago a large compression front passed through the area from an epoch of massive star formation in the Sco-Cen OB association, which occurred in 3 clumps between Antares and Crux. Then, about 1.5 million years ago a fast-moving supernova detonation wave blew past, triggering two star formation episodes. The first occurred about 1.5 million years ago when one star in an O supergiant binary system went supernova, kicking the other massive O star into the runaway star ζ Ophiuchi. The second episode is a very young T-Tauri protostar burst that started less than 300,000 years ago and is still ongoing. The M8 Lagoon nebular complex has a similar dual-episode history even now.

The dense L1688 dark cloud (contrarily shown as bright $H\alpha$ emission in the image to the right) reveals the star-forming effects of a rapid supernova shock. In the left-hand visual image we see a bowed shock wave strongly compressing gas along the front surface of a dense dark cloud. The same shape can be seen in photos of aircraft flying supersonically through dense humid air.



In the image to the right from the SOFIA flying observatory aboard a 747 jet airliner, we see how a single large shock pulse can trigger collect-and-collapse star formation in several places in close succession. These can become multiple star clusters reminiscent of the Perseus Double Cluster. We also see a tumultuous realignment of magnetic field lines due to shear and torsion energies as a physical shock bends and twists around dense gas pockets. While all this sounds—and is—a very violent process, it takes place over time spans far in excess of human recorded history. The ploughs that break the clods of a field are gone in a day. The ploughs that break the clods of the galaxies take a million years.

As serene and subtle as Yolanda’s ρ Oph image might seem, it is a miserable life out there. Temperatures in the clouds range from 13–22 K, ideal for forming molecular hydrogen out of two hydrogen atoms that can bond only through the catalytic electron-transfer prowess of CO or carbon monoxide. Since molecular H_2 radiates almost no energy on its own, we detect it via the presence of CO in cold clouds. The L1688 cloud above has enough H_2 to make a cluster of about 3,000 stars the mass of the Sun. The infant star cluster hiding in benign-seeming gas already has made 425 infrared young stellar objects, 16 protostars, and 200 T Tauri stars whose ages range from 100,000 to a million years.

tale of two clouds

The spectacularly writhing M20 Trifid Nebula contrasts sharply with the nearby open star cluster M21, Webb's Cross. They are not just visually different, they are genetically different as well.

The Trifid is one of the youngest star-forming regions in the Galaxy. At about 300,000 years old it is still deeply enshrouded in its birth or natal gas, which glows fiercely here in reddish ionised hydrogen alpha at 656.28 nm. The dark streaks are dust lanes that were once a thin flat sheet but have been twisted beyond recognition by the shears and twists of star formation. The Trifid is the product of two giant gas clouds colliding and passing through each other. The pressure surface where they scrunched into each other decoupled the dust from the gas and formed a dark pressure surface which then crumpled into the Trifid lanes. The gas clouds compressed into stars as they passed through each other.

Next-door M21 is a much older cluster at about 15 million years. Its few B-type stars blew away its natal gas millions of years ago, which is why it glitters so brightly in the eyepiece. M21 is a traditional collect-and-collapse cluster made by the free-fall collapse of a massive molecular cloud.

Further reading: Since galaxies are filled with so many gas clouds of many compositions and sizes, it is worth a bit of time to read up on them. Here are a few recent papers on cloud-cloud collisions. *Dobbs 2013*, and specifically for M20: *Torii 2016*. A *generalised Google search* produces many more.

To help visualise how two clouds of uniform gas can collide, flatten, and deform into dark lanes like the Trifid's see *Figs. 1–5 of this paper*.

Captured over several nights in July to August 2019 and June to July 2020. 401 x 3 min light frames at ISO200 with dark, bias, flat, and dark flat frames. Total integration time 20h 3m.

ngc 5367

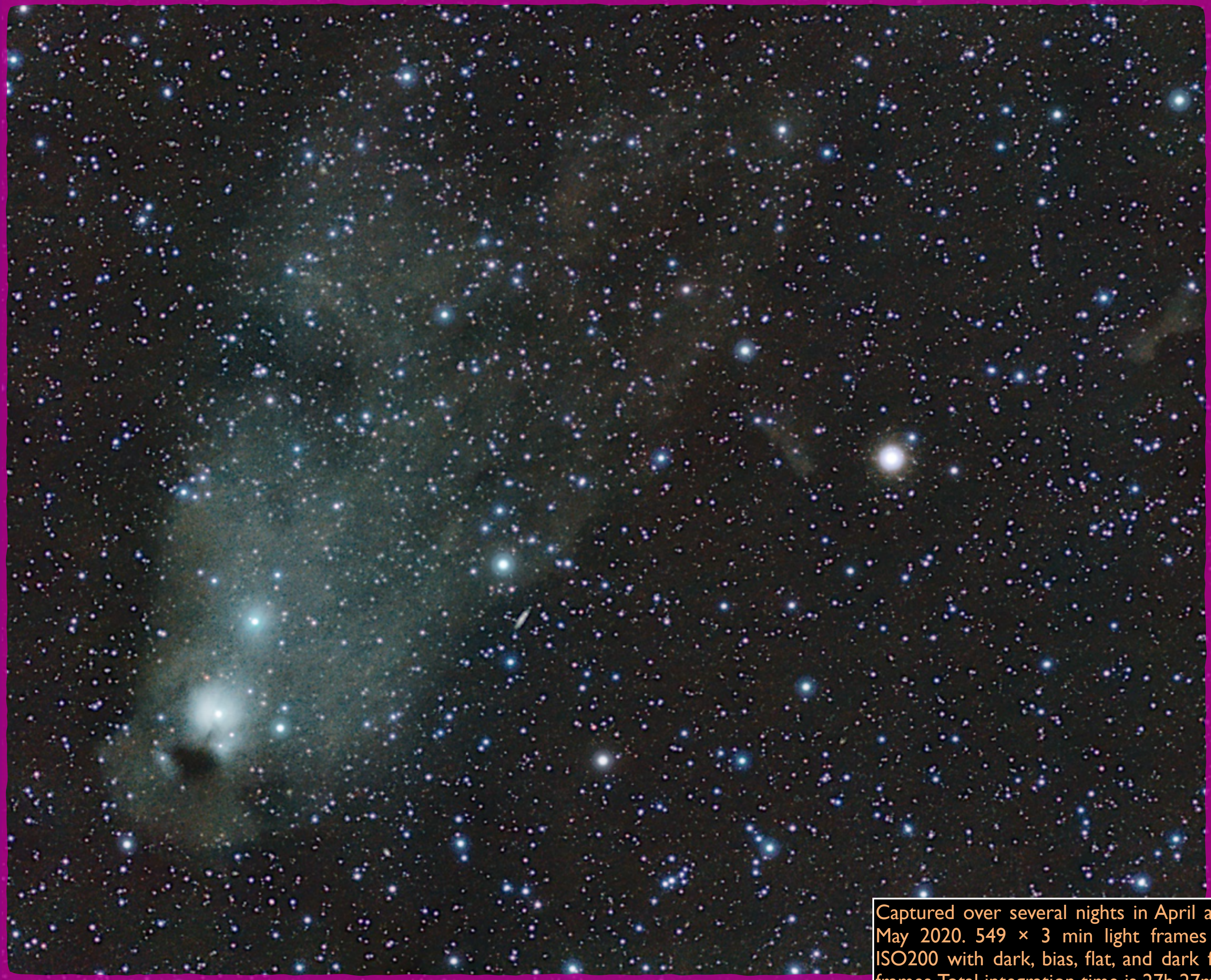
The inky blob at the tip of this comet-like emission nebula is *CG1*2. The acronym means 'Cometary Globule' (surprise). CG12 is located in the constellation of Centaurus and associated with the blue reflection nebula NGC 5367.

Cometary globules are tiny, very dense gas concentrations like the better-known *Bok Globules*. Bok Globules emit no light and hence are visible mainly when in juxtaposed front of bright emission nebulae (as in the M8 Lagoon image below).

Cometary Globules are visible to us due to their high- velocity passage through molecular gas clouds, which excites the gas they disturb, giving CGs their comet-like head-and-tail appearance. They emit much more brightly in ultraviolet bands than shown in Yolanda's optical-band image here.

The dark head in CG12 is not the brutally cold inkwell of opacity that it resembles. Stars are forming inside CG12 (as they also are in Bok Globules), but the overburden of dense gas around the infant stars is so opaque that it can extinguish 10 magnitudes of visible light. Even so, the hot young starbirth inside is detectable in millimetre wavebands and hence intensively studied by the ALMA Array in the Chilean Andes.

CG12 is not especially massive, nor are Boks. Most Boks are thought to form small multiple-star systems, up to a total of 100 solar masses, depending on the actual mass of available molecular hydrogen. *Read more here*.



Captured over several nights in April and May 2020. 549 × 3 min light frames at ISO200 with dark, bias, flat, and dark flat frames. Total integration time is 27h 27m.

m8 lagoon

The Lagoon Nebula is the very opposite of the languid seaside cove we usually associate with that word. Instead, we are looking at a cosmic conveyor belt of enormous length and mass. Star-forming hydrogen gas and dust are being funnelled along a cylindrical column shaped by the compression of the Milky Way's disc curling into the dense inside arm of the Scutum-Sagittarius density wave.

A star-forming galaxy's thin disc would rotate like a pancake if there was nothing to disturb it. Alas, a galaxy disc is chockablock with disturbances—supernovae shocks, infalling dwarf galaxies and million-star cold gas clouds, primordial hydrogen infalling along filaments of the *Cosmic Web*, thermal and magnetic shocks from star cluster formation, the tumescent energies of young star clusters birthing and dying.

In the M8 infall complex we see at least three massive star clusters that have formed sequentially over the past four million years. Just left of centre is the glittery diadems of NGC 6530. To the right and across the arc-like 'Lagoon' is the Hourglass Nebula, shocked into a frenzy of star making less than 200,000 years ago by the massive O supergiant Herschel 36. And totally invisible thus far is a third cluster so young that it does not even emit visible light as yet.

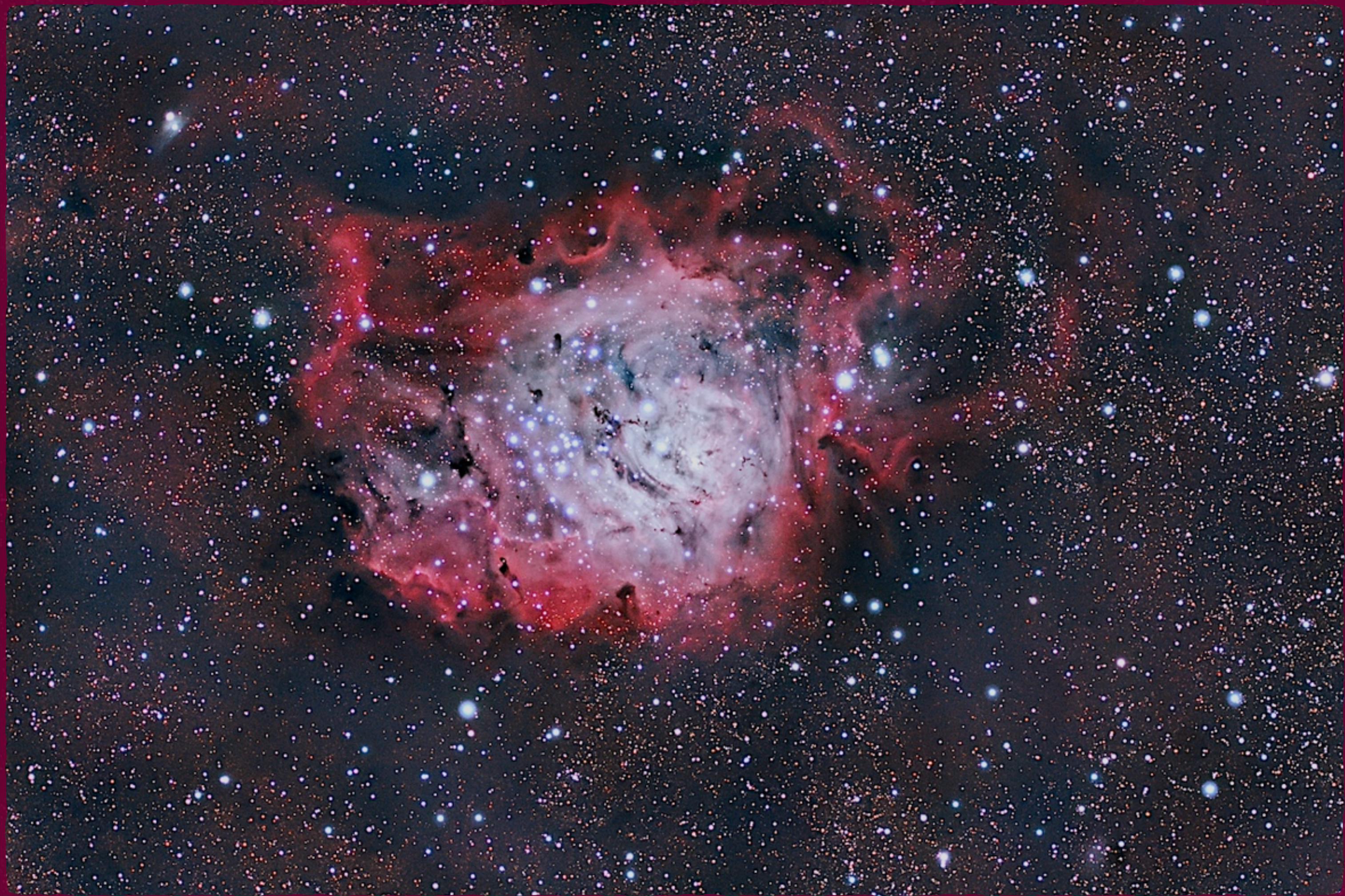


Image acquired over several nights in August to September 2019. 254 x 3 min light frames at ISO200 with dark, bias, flat and dark flat frames. Total integration time 12h 42m.

Centaurus A

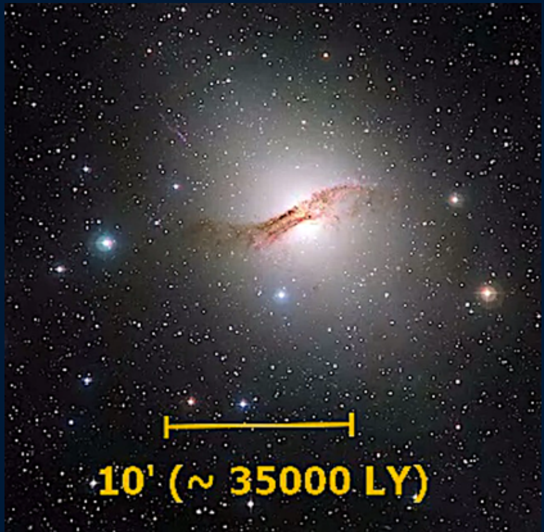
In this image, Yolanda puts us on a magic carpet ride back into the look-&-feel of monochrome glass-plate images before CCD photon capture technology and the scintillation technique of image stacking. The textbooks of basic astronomy produced during the 1940s to 1970s presented images of the *Centaurus Galaxy* as an enigmatic spheroid that looked like it crossed paths with a dusty spiral galaxy that somehow didn't have any stars.

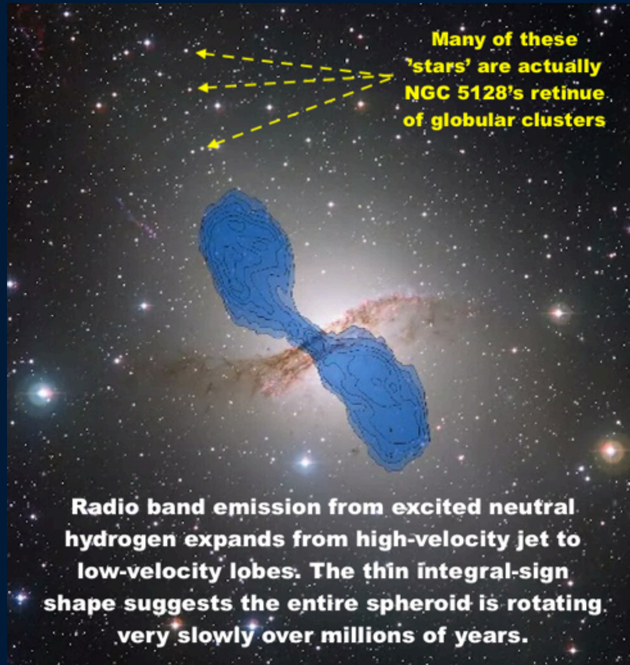
The subtle hint of modernity in Yolanda's image is the improvement in contrast dwindle in the outer environs of the spheroidal halo when compared with the density dispersion in pre-CCD blue- and red-sensitive emulsion films. Those emulsions could capture only about 7% of the total number of photons reaching them, while a typical off-the-shelf DSLR of today records up to 90% of the arriving photons.

Centaurus A (NGC 5128) is the 5th brightest galaxy in the sky. That is one reason why it is so often imaged. Its mysterious middle is a challenge.

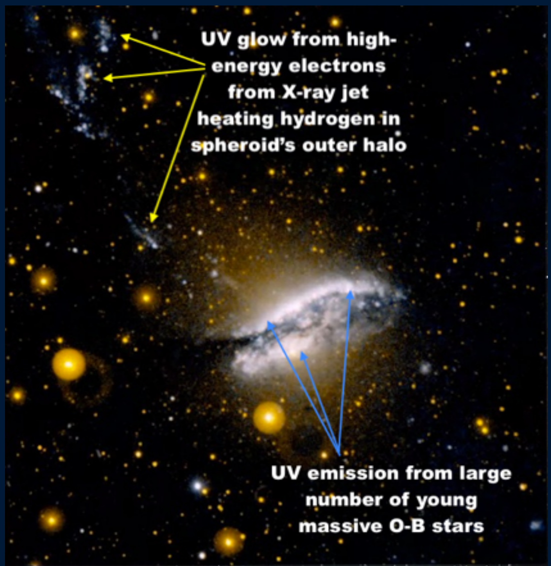
Acquired over several nights in April 2020. 261 x 3 min light frames at ISO200 with dark, bias, flat, and dark flat frames. Total integration time 13h 3m.

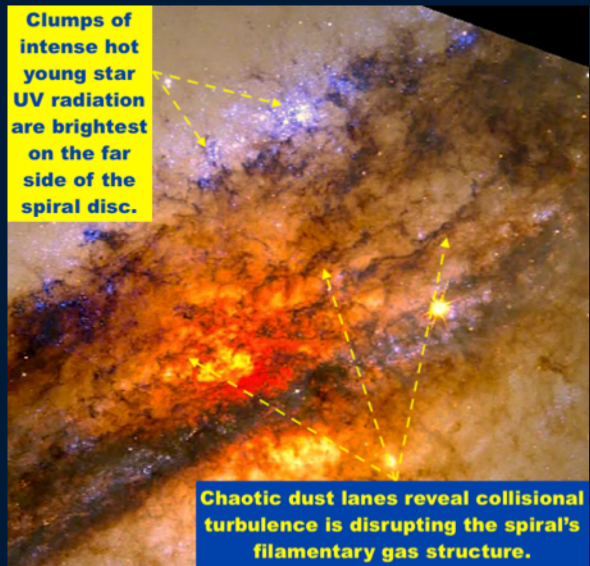
Centaurus A ancient elliptical component

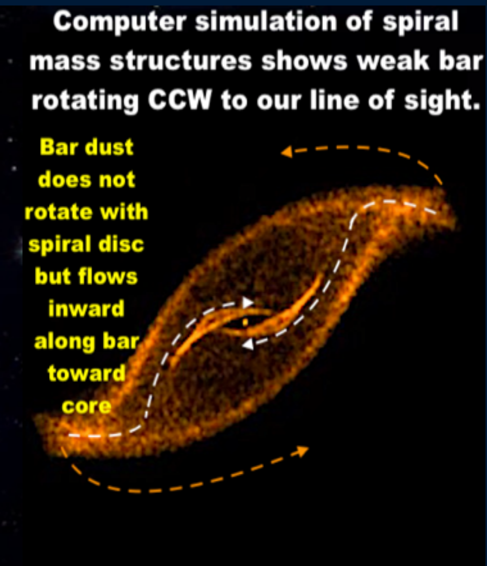


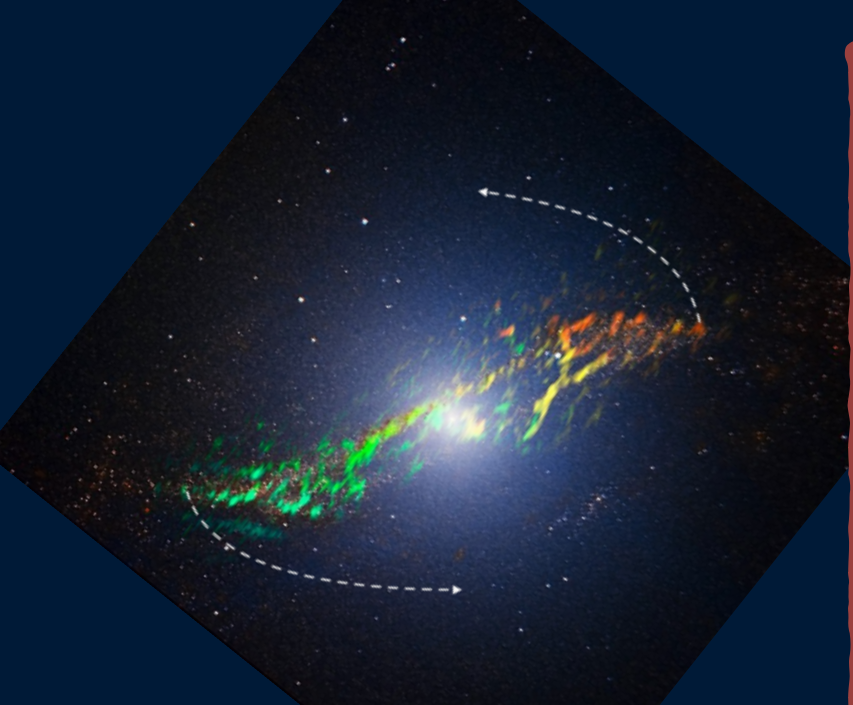


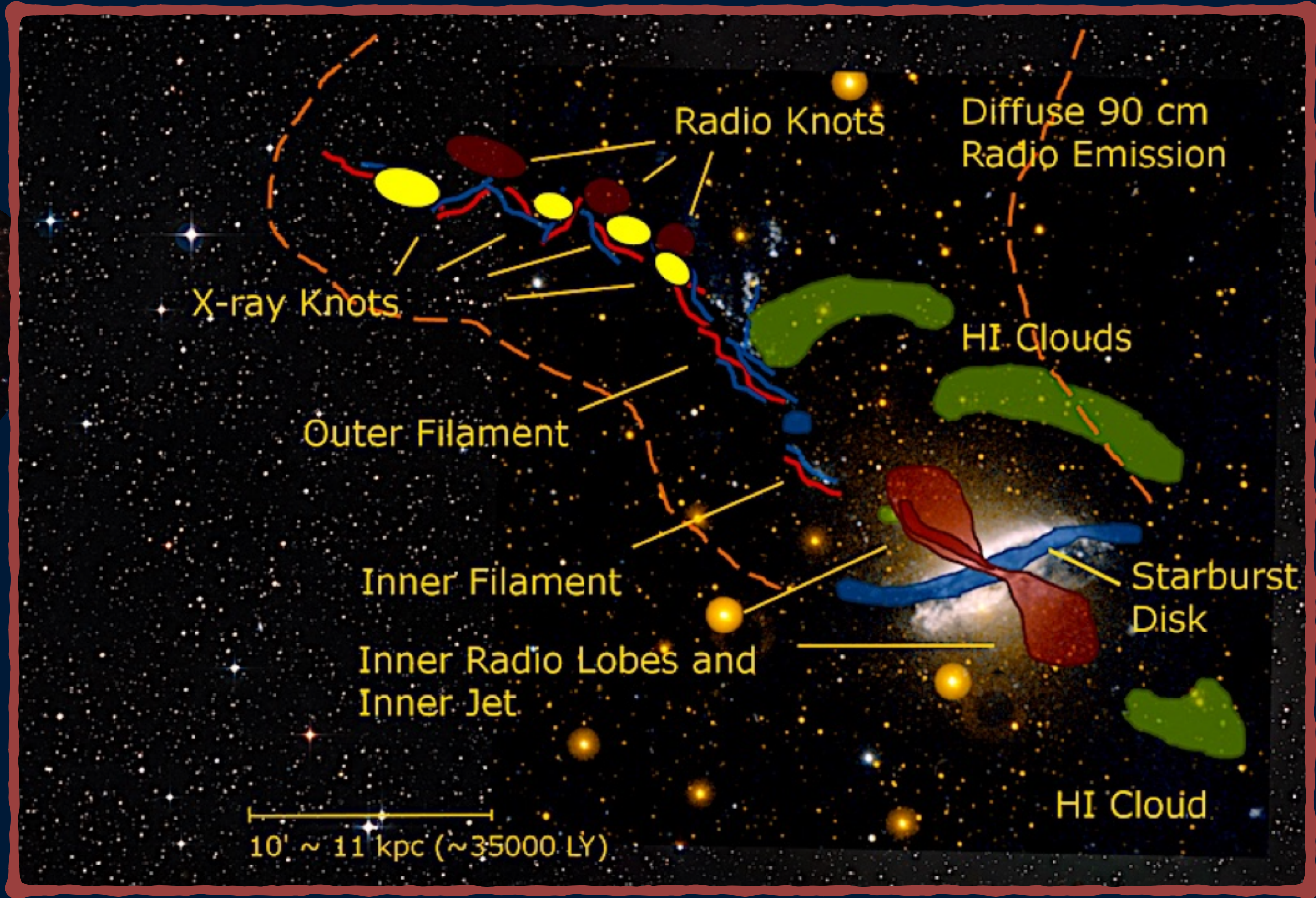
Cen A barred spiral disc galaxy component











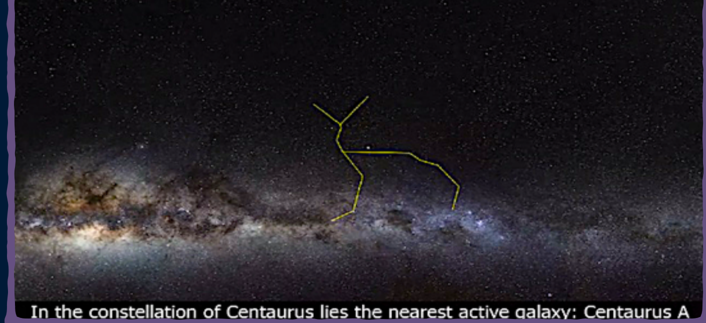
Cen A is so important to astrophysicists that Simbad lists an *astonishing 105 alternate identifiers* for it. Since institutional records of astronomical objects first began to be written down in permanent form starting in 1850, over 4043 papers in the professional literature have mentioned Centaurus A.

Cen A's unusual appearance was first pointed out by John Herschel in 1847. It was included in *Halton Arp*'s 1966 *Atlas of Peculiar Galaxies* as a 'disturbed' galaxy with dust absorption. In Yolanda's image—and dozens of others as far back as 1897—the Centaurus Galaxy NGC 5128 looks like a nearly spherical ancient elliptical galaxy that is either being intruded upon or is absorbing a young spiral galaxy with abundant dust lanes and an inexplicable absence of bright stars. The two galaxy types couldn't be more different. The elliptical galaxy long ago lost its star-forming gas due to multiple collisions with other galaxies. It now ages gradually toward extinction many Hubble times into the future.

The spiral component looks like a traditional dust-laden disc-and-bulge galaxy rather like our Milky Way. Its starless morphology was not clarified until the arrival of space-based telescopes in the 1990s that could record photons in X-ray, UV, and far infrared wave bands inaccessible on Earth because of our thick, wet atmosphere. The stars are there, but so hot they emit almost totally in ultraviolet.

Adding all the evidence together as shown on the previous page, we can now see that the spiral galaxy has already passed halfway through the spheroid, generating a fierce starburst of hot young stars above and below its obscuring dust lanes. Ironically, the spiral galaxy is being radically disrupted by all this, while the virtually gasless old spheroid is serenely watching the show with very little disruption on its own.

Don't miss this Cen A video simulation.



ngc 253

Dust has its privileges, at least in galaxies. Without it, there would not be very many galaxies. The simple primordial hydrogen atoms made just after the Big Bang repelled rather than attracted each other because their orbiting electrons all had the same electrical charge. Hydrogen atoms can combine into its star-making molecular form H_2 only on the surfaces of the myriad carbon-rich dust specks that beclotted the atmospheres of old, highly evolved *AGB stars* nearing the end of their lives. The first generation of stars could form only because the early universe was so very much denser than today. Once dust did become available in large quantities starting about 3 billion years after the Big Bang, galaxies rapidly burst into life amid the richest era of star formation in the universe's history.

When we see a heavily dust-clouded galaxy like the Sculptor Galaxy NGC 253 we are also seeing a galaxy that is so successful that it defeats its own ability to spawn new stars. Ultra-massive dust clouds like those seen here also make ultra-massive star clusters. NGC 253 has some of the most massive clusters in the local universe. The ultraviolet radiation from their hot young stars evaporates the very dust particles on which H_2 depends, thus in effect starving themselves of their future.

Captured over several nights in October to November 2019 and June 2020. 404 x 3 min light frames at ISO200 with dark, bias, flat and dark flat frames. Total integration time 20h 12m.

farewell frolic

M17 The Swan or Omega Nebula

Taken over several nights from July to September 2019 and May to July 2020. 470 x 3 min light frames at ISO 200 with dark, bias, flat, and dark flat frames. *Total integration time 23h 30m.*

M16 The Eagle Nebula

Captured over several nights in July 2019 and July to August 2020. 503 x 3 min light frames at ISO 200 with dark, bias, flat, and dark flat frames. *Total integration time 25h 9m.*

NGC 5139 Omega Centauri

Captured over several nights from February to April 2020. 210 x 3 min light frames at ISO 200 with dark, bias, flat, and dark flat frames. *Total integration time 10h 30m.*

Comet Neowise

Composite of
35 x 3 min light frames at ISO 200,
13 x 8s at ISO 1600,
7 x 6s at ISO 1600.
Stacked with dark, bias, flat, and dark flat frames.
Total integration time 1h 45m 26s.

NIGHTFALL

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