

*As the dome of twilight sinks below the horizon, a mechanical corps de ballet starts a slow-motion pirouette with each dancer keeping the unblinking eye of a telescope locked on a single spot in the heavens. Shutters open and ancient photons, ending a journey that may have started before the earth was born, collide with sensors, each of which marks that photon's arrival. With the dance in motion the directors sit back to watch the show; another imaging session has begun...*



*Image by Marcus Stevens*

# A Full and Proper Kit

An introduction to the gear of astro-photography

*The young recruit is silly – 'e thinks o' suicide;  
'E's lost his gutter-devil; 'e 'asn't got 'is pride;  
But day by day they kicks him, which 'elps 'im on a bit,  
Till 'e finds 'issel one mornin' with a full an' proper kit.*

Rudyard Kipling

Like the young recruit in Kipling's poem 'The 'Eathen', a deep-sky imaging beginner starts with little in the way of equipment or skill. With 'older' imagers urging him onward, providing him with the benefit of the mistakes that they had made during their journey and allowing him access to the equipment they've built or collected, the newcomer gains the 'equipment' he needs, be it gear or skills, to excel at the art. At that time he has acquired a 'full and proper kit' and ceases to be a recruit.

This paper is a discussion of hardware, software, methods and actions that a newcomer might find useful. It is not meant to be an in-depth discussion of all forms of astro-photography; that would take many books and more knowledge than I have available. But I hope that my descriptions and graphics will help a newcomer to the art understand a bit more what is involved in this wonderful pastime.

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December 2010

*My thanks to the Royal Astronomical Society of Canada London Centre for their input and support and especially Matt Neima and Chris Evans for taking on the task of sorting out my typos, grammar glitches and oddities of syntax.*

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## HARDWARE SECTION

A cursory introduction to the hardware that imagers use.

*Downtown Milky Way by Jon Gunning*

# Telescope Mounts

**The foundation of astro-photography is the mount.  
An amateur imaging mount has to be equatorial.**

In the world of amateur astro-photography the two statements above are axiomatic. A weak mounting can deliver good images under perfect conditions and for some types of imaging one can get away without an equatorial mount. For most applications though a strong, well-built equatorial mount is still optimal.

What is an equatorial mount? An equatorial mounting allows a telescope to accurately track the sky as the earth rotates but not all tracking mounts are equatorial. For an example of a non-equatorial mount think of a camera tripod. Most camera tripods allow a camera to move so that it tilts up and down, and swivels side-to-side. In astronomy this is known as an altitude-azimuth (alt-az) mounting system. To track the stars a mounting of this type needs to move both axes in concert which many do, but these are not optimal for astro-photography (see the panel at the end of this chapter).



Fig. 1

To turn an alt-az mounting into an equatorial mount it needs to be tilted so that the vertical axis is now parallel to the earth's rotational axis (through the poles). The axis that swivelled parallel to the horizon now moves parallel to the celestial equator hence the name 'equatorial'. This type of mounting allows the telescope to track with the rotation of the earth by only moving a single axis.

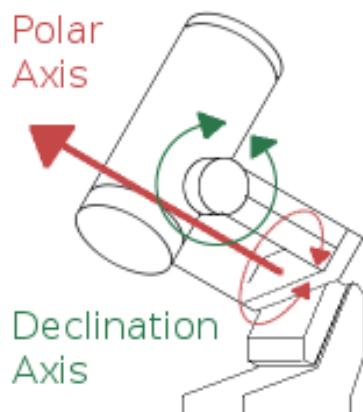


Fig. 2

Two types of equatorial mounts are most commonly used in the world of amateur astro-photography; the fork mount and the German equatorial mount (GEM). Other types such as the split-yoke and English cross-bar while good designs, have generally not been widely offered commercially.

Fork mounts look like large tuning forks with the telescope tube riding between the tines. These were made famous by Celestron and Meade, both of whom offered their Schmidt-Cassegrain telescopes mounted in this fashion. Over the years many thousands of fork-mounted telescopes have been put to good use in the field.

Figure 1 on the previous page shows a Meade LX200 owned by Chip Frappier of Manatee, FL. The fork mount is riding on a structure called an equatorial wedge which tips the mount so that the polar axis, which is parallel to the fork tines, is in-line with the earth's axis. Equatorial wedges are generally adjustable for different latitudes and good ones will be very sturdy. The declination axis runs through the centre of the telescope at the top of the fork arms.



*Fig. 3*

telescope to balance the load.

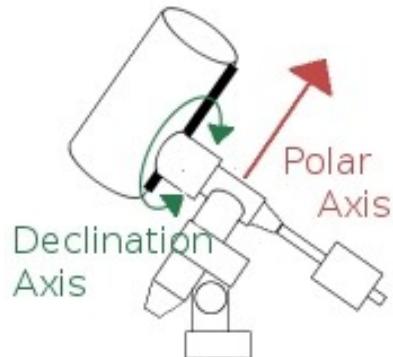
One limitation of a fork mount is the length of the forks themselves. They should be short enough to mitigate any 'ringing' or vibration yet long enough to allow a camera to swing through them as needed. This means that some thought has to be taken in the design of the forks. Something to be taken into consideration.

The second type of common mounting is the German equatorial mount. These are by far the most common mount types sold to people that have their own optical tube.

German equatorials such as that shown in Figure 3 have a polar axis that is adjustable for latitude and carry the declination axis at the north end. The declination axis is set perpendicular to the polar axis and carries the telescope mounting system on one end with a counterweight shaft opposite it. This layout allows for a lot of versatility in the type and weight of telescope systems that can be carried.

Some fork mounts may have limitations as to where they can be pointed with a camera attached on a Schmidt-Cassegrain such as the one shown. Notice that the camera would have to be able to swing through the forks at some orientations. This may limit imaging in the area of the celestial pole. Also, when the telescope is pointed at the zenith it may be difficult to focus a DSLR camera just because of the position of the camera with reference to the tripod.

While no counterweights are provided with fork-mounted telescopes some weights may have to be added. As the optical tube generally cannot be moved in the forks placing a heavy load on the rear of the telescope may cause problems in some orientations. Accessory kits can be purchased to add weights along a bar that runs under the



*Fig. 4*

While GEMs don't have the 'swing through' limitation that fork mounts have they may be limited in other ways. Owing to the design a telescope tube may come into contact with a tripod leg in some orientations, generally near the meridian. This forces an evolution known as a meridian flip where the

mount 'turns over' to put the optics on the opposite side of the mount. Some mounts use software limits to mitigate this, others use micro-switches which actually stop the mount tracking at or near the meridian.

Whichever the type in use size does actually matter when it comes to a mount for astro-photography. The more mass there is in the mounting generally the more stable the mount is; and stability is king. There is a caveat here; a lot of mass in the weight in the mounts head won't help if the legs of the tripod or the pier are too light or aren't stiff enough. While some folks can get good output from lightweight mounts something with a bit more avoirdupois makes life easier.

A simple test for the stability of a telescope mount is the 'thwack test'. Firstly load the mount with ALL of the gear that it will be carrying for an imaging session except for the camera. Place an eyepiece in the telescope and focus on a star. Now, while looking at the star, give the optical tube a good smack with the flat of your hand and count the number of seconds that it takes for the telescope to settle; the lower the number the better. Of course, if the telescope belongs to someone else be sure to ask permission first.

The payload capacity of a mount is extremely important but the numbers offered by many manufacturers can be misleading. Generally they tend to state the most that their mount can carry for visual observations (and I'd disagree with most of them in that respect anyway) as this allows them to quote overly large numbers. For most non-premium mounts the rule of thumb is to take the stated payload capacity and cut it in half. This will give a realistic limit on what the mount can carry for imaging.

When thinking about a telescope mount always look into the future. Never expect that the equipment that is on hand now will remain the same down the road. I like to think that the weight of equipment, even with the same optical tube, will grow by about 50% over time. So if there is 15 kg of equipment to be carried look for a mount that will (after cutting the number in half) carry 22 kg of payload. That way a mount can stay in operation a lot longer.

Many mounts these days are equipped with some form of 'goto' system. This means that once the mount has been told where it is in space-time (location and date/time) it can be configured to allow it to automatically slew to a selected object, an object which usually resides in a database held in the telescope's electronics. For imaging 'goto' is not required but it is very useful if trying to image something that can't be seen in the camera viewfinder or in a finder scope.

The different 'goto' systems offered by each telescope manufacturer all have their own strengths and weaknesses. Celestron's NexStar system is very user friendly as is the Meade AutoStar system. The system that Losmandy uses is called Gemini, a third-party system which is also used on several other makes of mount.

A mount that is to be used for astro-photography should have an auto-guiding port. Not many people take unguided images these days and having a dedicated port to plug an auto-guiding device into increases the

flexibility of equipment that can be used. In any case a mount that can be controlled by a computer may be able to be guided using standard computer control commands without a dedicated port.

Polar alignment is made much simpler if the mount has some form of polar alignment telescope such as that shown in Figure 5. These are generally small refractors that are mounted inside the polar shaft of the mount and have an illuminated reticule that, when properly adjusted, allows a mount to be accurately aligned with the earth's axis. Some of these are better than others but none of them will work unless properly centred in the axis and, for some, having date/time rings properly setup. This type of setup is shown to the right.

To help with getting your mount's Goto system properly setup, almost all telescope mount makers now offer some form of GPS unit that provides the mount with its position and an accurate time source. My Celestron CGE's slews became much more accurate when I didn't have to enter my own latitude and longitude then use my wristwatch for the current time. If the mount is going 'on the road' a GPS makes life a lot easier; no more envelopes with hastily scribbled position information.

The ability to connect a mount to a computer is very nice to have. While I do most of my imaging in the field where I don't carry a computer I do make extensive use of my laptop during my visits to a friends house in Indiana. Working from the warmth (or cool depending on season) of his shop makes life a lot easier during turn of the season sessions. Also, having a fridge full of refreshments and good music playing makes imaging almost civilized, but I digress.

Even in the field computer control of the mount can be an advantage as there is access to planetarium software to peruse to find targets which can then be sent to the telescope to slew to. I use star charts at our dark-sky site, but believe me, it's much nicer looking at the computer display.

Generally, computers 'talk' to mounts using a serial communications protocol. As not many laptops these days have serial ports, a USB to RS-232 adaptor will be required. Some reports tell us that not all work with all mounts and laptops. I haven't had this experience but it is always good to check the on-line forums to see if anyone has had issues with a prospective purchase. The mount and software have to be using the same communications parameters which will be outlined in the mount's documentation.

At times an old argument pops up as to whether it's better to have servo motors or stepper motors driving a mount. For those that are unclear on the difference a servo motor is a DC motor that has an attached encoder of some kind that runs in a control loop. The circuitry monitors the position and speed of the motor constantly and adjusts things as needed to keep the mount pointed correctly. Stepper



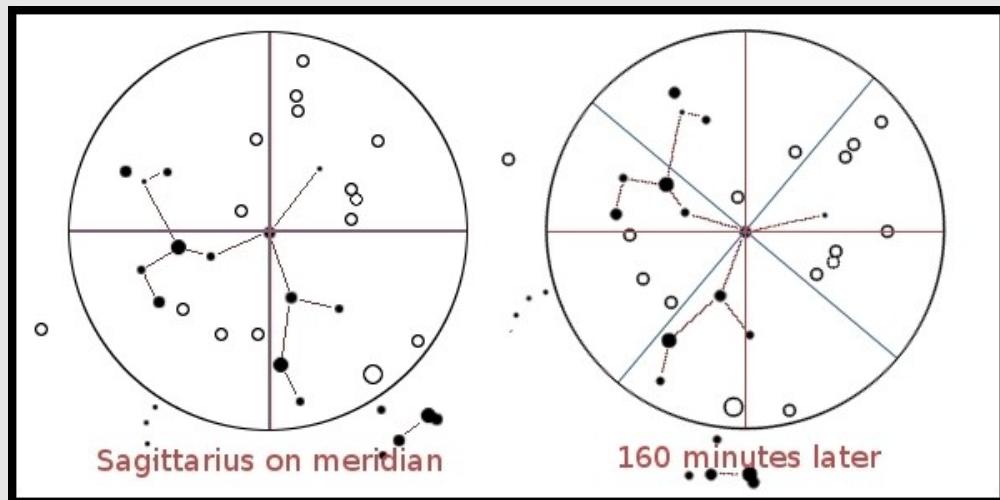
Fig. 5

motors 'pulse' in small, discrete values such as 1.8 degrees per step; or 200 steps per revolution. For these the mount's circuitry calculates how many steps per second it needs to turn to track and sends the correctly timed pulses to the motor. To slew the mount the electronics calculates how many steps are needed to perform the slew correctly and then sends that number of pulses to the motor. While it may seem that a mount that 'steps' might be choppy, a stepper motor can run in  $\frac{1}{2}$  step mode or can be micro-stepped to the point where they are as smooth as DC motors. Some high-end imaging mounts use steppers (notably Takahashi) where others use servo-motors. If the circuitry is designed well it doesn't matter.

### Why do I need an equatorial mount?

With all of the alt-azimuth mounts on the market that can very accurately track the sky why is an equatorially mounted telescope necessary? The answer is short and is known as 'field rotation'. Any mount that does not have an axis accurately aligned with the earth's axis will have a field of view that rotates. For astro-photographers their image will actually rotate around their guide-star.

Field rotation exists because the optical tube on an alt-az mount doesn't rotate in sync with the sky as it wheels overhead. The graphics tell the tale. The blue cross hairs would be on a polar-aligned equatorially mounted telescope and the red cross hairs from a tracking alt-azimuth mounted telescope.



While large, professional scopes these days ride mostly on alt-azimuth mounts they also incorporate some very high-tech and accurate method of rotating their imaging platform to negate the rotation imparted by the mount. Amateur field de-rotators do exist but they generally don't work very well and an equatorial platform is always the best choice.

## Tripods and Piers

Some telescope mount manufacturers or vendors offer a choice of either a tripod or a portable pier. Which is better is a function of the primary use of the mount. Will it be placed in a semi-permanent setting such as a roll-off roof observatory or SkyPod or will it primarily have to be transported to a dark-sky site for use?

For the semi-permanent setup a portable would be quite acceptable as long as it is properly designed and that design carried out correctly. The Astro-Physics pier shown in Figure 6. is a very good pier, properly braced and very stiff. The only thing lacking in my mind is some method of levelling it on uneven ground. Not being designed to be hauled around this is not a huge problem, but it is something to think about if a setup is going to be mobile at any time.



Fig. 6

Tripods are, in my estimation, are a much better choice for an imaging setup that is going to move from site to site. Most offer a great deal of adjustment for level on unprepared ground and are very easy to site for proper orientation.

A properly braced and tensioned tripod is as stable as most portable piers and much more stable than some. A tripod should, when setup and tensioned, act as a single, monolithic structure. The better ones have two sets of braces spaced vertically. One of these will push outward evenly on the tripod legs and the second will pull inwards against the push of the other. These effectively pre-load the tripod so that it becomes extremely rigid. Figure 7 represents the CGE tripod which is one of the best designs that I've seen. The brace and spreader are seen with red arrows showing the forces created.

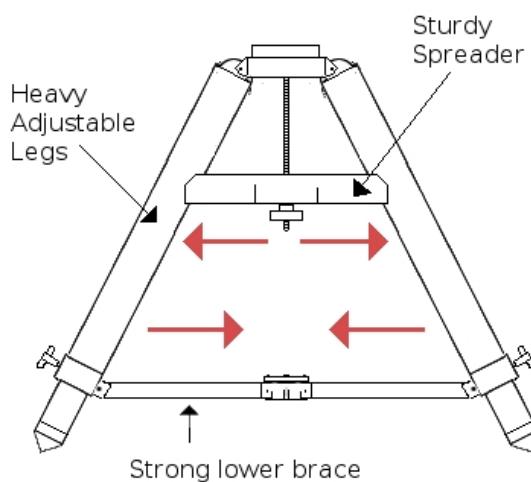


Fig. 7

Tripods come with legs fabricated from many different alloys, composite materials or wood. For heavy loads, cold-rolled steel is the best in my opinion. These offer a lot of mass, rigidity and strength and don't become brittle if being used in extremely cold temperatures. Wood is very good for a light or medium duty tripod if the wood is properly selected. Species like oak or mahogany are strong and offer very good damping characteristics. I would stay away from aluminum if only for the lack of suitable mass for an imaging tripod.

With the amount of gear that tends to be used while imaging some sort of shelf or platform is almost de rigueur and several companies offer a replacement spreader for tripods that also act as accessory shelves. One of the best I've seen (Figure 8) is made for the CGE and was offered by Starizona. They have sadly discontinued this product but one of the denizens of the CGE Yahoo! group has taken up building these in his shop.

Another very good accessory that should be part of any imager's kit is a lower accessory tray. These can come with or without a spreader and Telescope Performance Improvements offers a wonderful unit that will fit most Celestron, Meade, and SkyWatcher/Orion mounts. As seen in Figure 9 they are perfect for keeping a battery off the ground.



*Fig. 9*



*Fig. 8*

Many tripods come with pointed ends on the legs, or they have plastic or rubber covered 'knobs' on the end. On unprepared ground these can slowly dig in during an imaging session causing drift in the images. A simple way to remedy this is to carry a few bits of plywood that can be laid on the ground underneath the tripod feet. Some ingenuity of design might be needed to keep the legs from sliding on the wood and the wood sliding on the ground.

Another method of keeping the legs from digging in would be to use a set of the anti-vibration 'pucks' that are sold by Celestron, Meade and Orion. These go under the tripod legs and will keep them from digging in though I really wonder if the flexibility designed into these could create any issues.

The last thing I will mention about tripods is Velcro. There can never be enough places to hang things like flashlights, intervalometers, USB hubs etc. and Velcro is perfect. I put squares of industrial strength Velcro on just about every flat surface on my mount and at least two on each tripod leg.

## Periodic Error

A favourite discussion in the on-line forums is periodic error (PE). This is a tracking error caused by slight inaccuracies in the mounts RA worm gear which can make the mount speed up and slow down very slightly causing a target to 'wobble' back and forth in right ascension. Some mounts exhibit a lot of PE and some don't. Even within a specific make and model the PE will be different from mount to mount.

A worm and gear come in two parts as shown in Figure 10. The worm is the driving part, in the image at right the gear at the bottom attached to the shaft. The gear, or wheel, is the driven part; the large gear at the top. The image shows that there are two periods of rotation in a worm and gear set; that of the worm turning and that of the gear turning. PE as related to telescopes is almost always stated as error in the worm and therefore the period of the error curve is that of the worm.

As no gears are perfect there will be some error in any gear-set, though as always some are better than others. This can be an error in concentricity, a slight change in the angle of the worm's teeth or a bump or other imperfection in a tooth. Any error will manifest itself in a wobbling back and forth of a star in the RA axis as shown in Figure 11. If plotted over time this wobbling will show itself as a sine-like curve.



Fig. 10

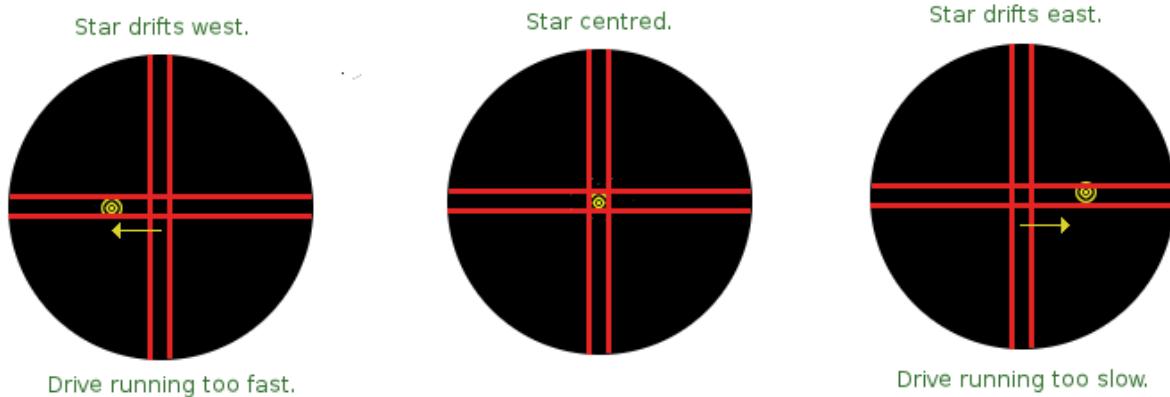


Fig. 11

The PE curve will have an amplitude of the greatest excursion of the star from centre and will have a period of that of the worm which can be calculated thusly:

$$86164 / \text{number of teeth in the worm gear}$$

So, a gear with 180 teeth will have a worm period of 479 seconds while a gear with 360 teeth will have a period of 239 seconds. A telescope mount's documentation will generally tell both how many teeth are on the worm gear and possibly the average PE the manufacturer puts on that mount.

Shown in Figure 12 are two PE curves both of which have a peak-to-valley amplitude of about 30 arcseconds. This is a lot but not unheard of with today's telescopes. The curve on the left is a perfect sine curve while the one on the right is more representative of what an actual smoothed PE curve would look like.

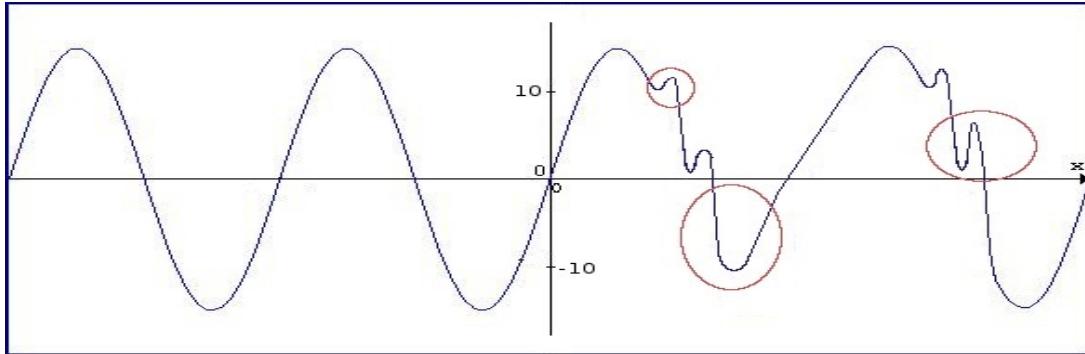


Fig. 12

Today just about everyone is guiding their images so normally any PE should be guided out. The amount (amplitude of the PE curve) of PE (the amplitude of the curve) isn't generally an issue but more important is the shape of the PE curve. The chart on the right shows a few areas where the curve is so steep that an auto-guider may not be able to correct for the changes quickly enough. These are circled.

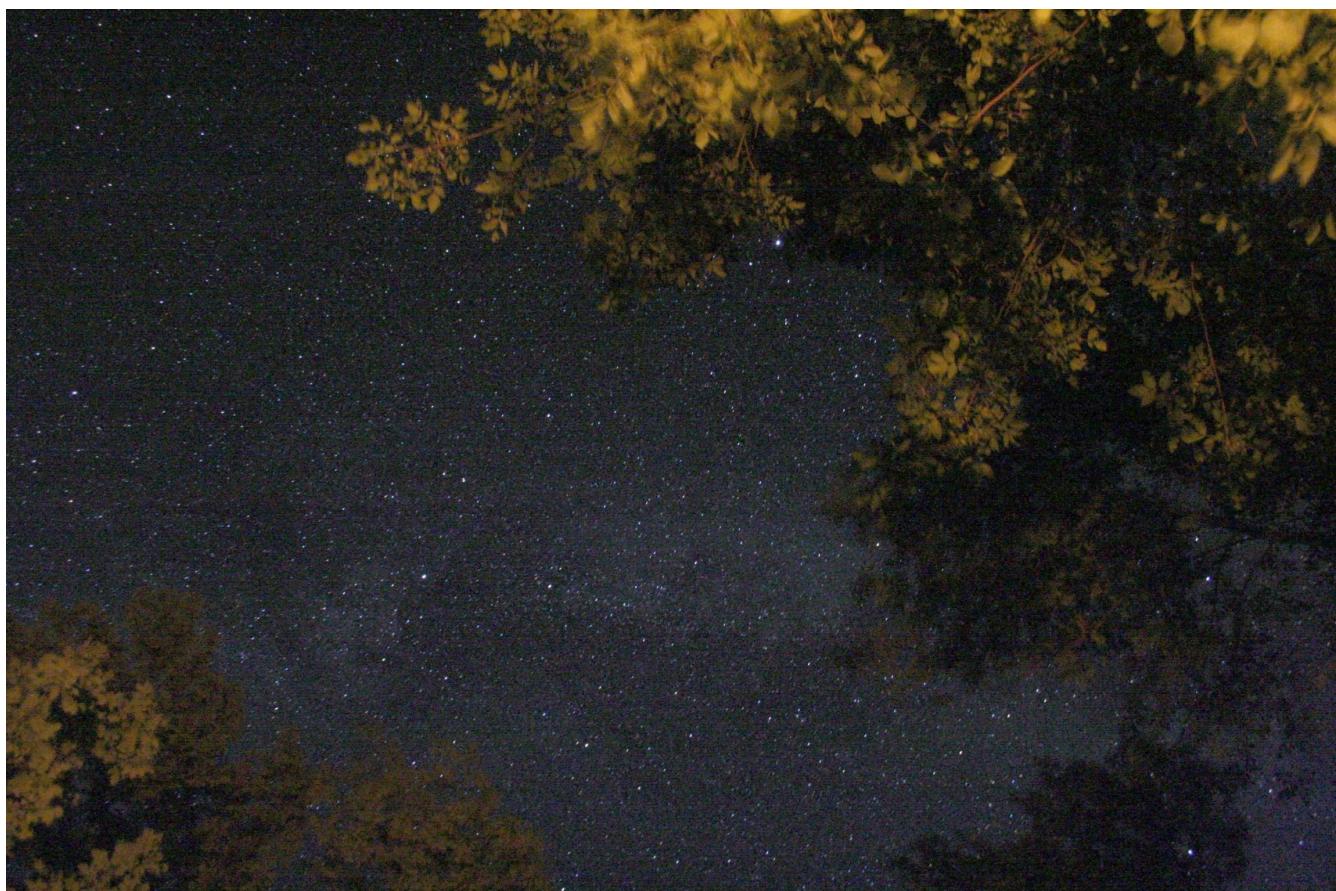
Even with a PE curve like the one on the right side a mount may still be usable for imaging as most mounts these days come with some form of periodic error correction (PEC) built into their firmware. PEC has always been a rather dark art to me and I never really did get it to work properly on my HEQ5 and I don't even try on my CGE; it isn't needed. The theory of how it works is quite simple. Start the mount's PEC 'learn' routine and let the mount run over three or four worm revolutions while guiding on a star (or let an auto guider do the work). While in learning mode, the PEC system records any guiding done. Once stored to use the data the PEC system is turned onto 'playback' and any guiding that was recorded is used by the mount's firmware, speeding up and slowing down as needed to smooth out the curve.

The problem with PEC while using an auto guider is that the guider, during its calibration phase, is doing its calculations with no knowledge of any worm rotation speed changes. If the mount is being guided during times of very slow or very fast worm rotation, as dictated by the PEC routines, then

guider error could be introduced. This may or may not be an issue and SBIG has in the past stated that PEC should be turned off when using their guiders.

So how good is PEC? Generally quite good from the examples I've seen where people have taken their time and used software tools correctly. With very good mounts PEC can reduce error to the point where an auto guider isn't needed for short(ish) exposures which makes it good for survey or patrol duties. It's not good enough for long-exposure imaging with any mounts that normal humans can afford.

There are several tools available to help with both determining the amount of PE a mount exhibits and to help with the mount's PEC routines to smooth it out. If the plan is to use both PEC and an auto guider it would be in their best interest to check the on-line forums to see if there will be any issues.



*Patrick Whelan of London took this image with his Canon XT through the trees using a tripod and the 18-55 mm kit lens.*

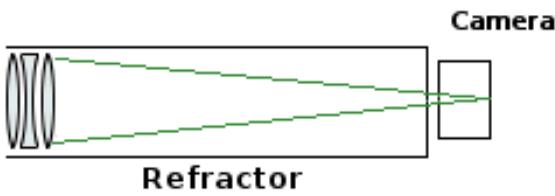
# Optics and Optical Tubes

Optics is a subject I hate giving any advice on as it is akin to religion or politics. The 'refractor vs reflector' wars rage unabated on many astronomy forums and they probably always will. Here goes.

Optics have come a long way since I started out in this astronomy addiction. Today there are literally dozens of good *and* reasonably priced telescopes on the market that would do admirably as astrographs. For wide fields there are short-focus apochromatic refractors from many manufacturers and even what once were exotic reflective systems such as the Ritchey-Chretien type are being sold at prices most can afford.

Optical systems generally come in three types. Refractors, those telescopes that use a lens or several lenses to form an image; reflectors which use a mirror or mirrors to do this and the hybrid catadioptric systems that use a mixture of both. Which is 'best' depends on what is to be imaged and how much abuse ones pocketbook can handle. Let's have a look at them.

## Refractors



As mentioned above refracting telescopes use a lens system to focus light. The simplest would be those such as Galileo first used to look at the Moon and consist of a single lens objective in the front and a single lens eyepiece at the rear. Simple but not much good for capturing any images.

Refractors generally have smaller light grasp than any of the others only for the fact that middle-aperture (8") lenses are prohibitively expensive and anything larger

Fig. 13

becomes unwieldy. Most of today's refractors being sold have apertures between 80 and 150 mm (3.1 to 5 inches).

It is my opinion the new small-aperture refractors are the best of the portable astrographs. If ones idea of refractors stems from the days of Unitron's beautiful doublets that stretched out to f/15 or beyond they will almost find it hard to recognize today's offerings. Short f/4 to f/8 tubes that fill dazzlingly wide fields with diamond-dust stars are the norm now. The glass in these telescopes comes in the form of doublets, triplets and Petzvals (4-element) and more are gracing mounts around the world than ever in the past; and turning out images that are stunning.

Most modern objective lens systems are well corrected for spherical aberration and coma. The many ED doublets are also well corrected for secondary spectrum (false colour) and today's apochromatic objectives will show no false colour at all. The one aberration these telescopes *will* show is curvature of field. Most refractor vendors also offer a field flattener to correct this, usually combined with a focal

reducer. The focal reducer function just gives the optics a wider field of view (see section on flatteners and reducers)..

Refractors, having nothing impinging on the incoming light, do not show the cross shaped diffraction spikes that other telescopes exhibit near bright stars. Also, having no central obstruction, refractors provide the highest contrast images of all astrographs.

Having a lens at the front of the tube means that refractors are susceptible to dew. To combat this and to ward off stray light most have a long shield that protects the objective lens from seeing too much sky. This can slow the development of dew but won't stave it off forever. Active dew control has to be taken into account with all refractors that are used in humid conditions. A refractor's closed tube means that tube currents are generally not an issue and with the objective out front the glass cools quickly.

Today's refractors come in three classes, achromatic, ED doublets and apochromatic with several types of apochromats. I include ED doublets as a separate class from 'apos'. This is one of my pet peeves as just about every maker of a doublet (two element) refractor with a piece of extra-low-dispersion (ED) glass in it calls their offering 'apochromatic'. There being no laws against telescope makers doing this the unwary purchaser can be taken in. While a properly designed doublet can indeed be apochromatic most aren't. Honest makers will just call them 'ED Doublets' and not apos.

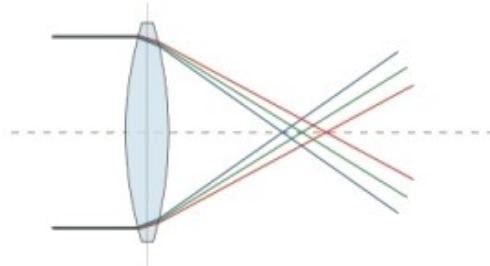


Fig. 14

Different types of refractors have lens systems designed and built generally to meet two criteria; firstly to reduce secondary spectrum (chromatic aberration) and secondly to provide increased flat field of view.

Chromatic aberration (CA), Figure 14, is caused by light of different wavelengths of light to come to a different focus. This means that the edges of bright objects show 'fringes' of colour.

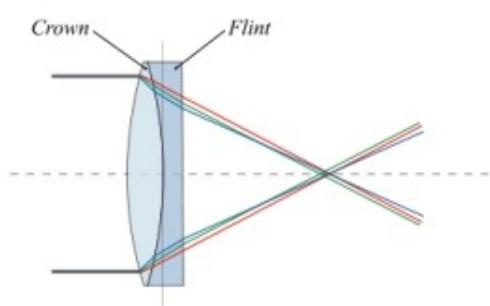


Fig. 15

In order to fight CA the achromatic doublet, Figure 15, was invented. This used two glasses of different refractive and dispersive properties, known as crown and flint, to allow the light of two widely spaced wavelengths to come to a single focus. This greatly reduced the fringing. With a standard achromatic doublet the shorter the focal length (hence wider field) the greater the effects of CA. In the past achromatic refractors had focal ratios of around f/15 in order to reduce CA even further.

While several designs of achromatic doublet came into existence in the early years of astronomical telescopes, the design of Fraunhofer is the most common now.

The Fraunhofer doublet has a front element of crown glass and a rear element of flint glass with an airspace in between them. The curves are all spherical but of different radii in order to fight ghost images. Other makers played with the Fraunhofer increasing the airspace (Clark) or even reducing the airspace or filling it with an optical quality oil.



Fig. 16

To minimize chromatic aberration achromatic refractors should be at a focal ratio of f/10 or greater but this doesn't mean that a short tube refractor can't take stunning images. Some very good f/6 or f/7 achromats do exist though they can't get away from the 'blue goo' of fringing around any brightish stars. Use them with a minus-violet filter to reduce this effect. Figure 16 was taken with an unmodified camera through a Stellarvue Nighthawk II 80 mm f/6 achromat.

An offshoot of the standard achromatic doublet is the 'ED

'doublet' offered by many manufacturers and sometimes marketed as 'apoachromatic'. These use carefully designed lenses with the front element being made of one of the extra low dispersion glasses matched with a proper flint (rear element) to reduce CA to very low levels. I challenge any of the less expensive ED doublets to meet either Abbe's or Back's criteria. My Stellarvue SV102ED which would be called apoachromatic by most makers is called only an ED Doublet by Stellarvue who also makes true apoachromatic refractors (triplets usually).

Abbe defined apoachromatism as follows:

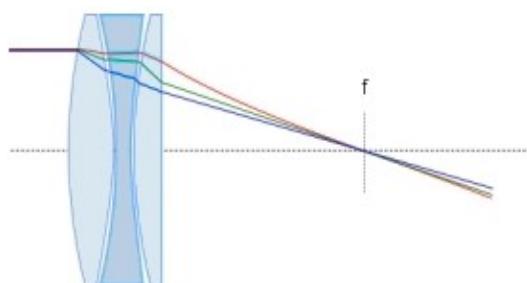


Fig. 17

**An apoachromatic objective will be corrected parfocally for three widely spaced wavelengths and corrected for spherical aberration and coma for two widely separated wavelengths.**

Any refractor that meets these criteria will show no secondary spectrum or 'false colour' when observing or imaging bright objects. The late Thomas Back expanded on this once in a paper basically saying that any optical system

that met stringent image quality criteria could truthfully be called 'apoachromatic'... his criteria were a bit different than Abbe's but basically said 'no false colour'.

The first commercial apoachromatic triplet was designed and built by John Dollond of London in 1763. Using three elements allowed the optician to have two colour crossings and therefore bring three widely spaced wavelengths of light to a single focus. Modern triplets show almost no false colour. The triplet shown at the left is of the Dollond (later called Cooke) design.

Using three lenses allows a great flexibility of design for the optician and these can be of very fast focal ratio providing a large well-corrected field.

Modern triplets all use some form of extra-low dispersion centre element such as FPL-53 or an equivalent; or possibly an element of calcium fluorite. The availability of exotic glasses these days has provided for some truly stunning images.

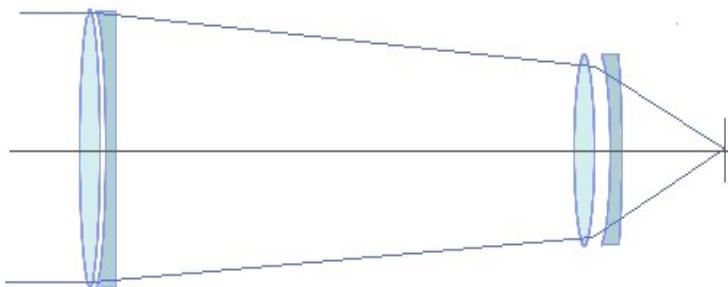


Fig. 18

The last apoachromatic type that is becoming more common, in that several makers offer them, is the Petzval type. This type of telescope uses two doublets very widely spaced; often at opposite ends of the tube. The front element in the best will be an apoachromatic doublet (they do exist, usually

with a fluorite element) with a focal length in the f/10 to f/15 range and the rear doublet which may or may not use exotic glass will decrease the total focal length to the f/4 to f/5 range. The Takahashi 'Q' types are of this style.

Refractors display other aberrations such as coma, spherical aberration and curvature of field. Very well designed refractive systems can reduce or eradicate most of these to a high degree. The major detriment of refractors is the very high dollar per inch aperture. A good 100 mm refractor can cost more than a good 400 mm Newtonian reflector.

## Reflectors

Reflecting optical systems use curved mirrors to focus light instead of the curved glass lenses of the refractor. These have many advantages over refractive systems and some detriments. The biggest advantages that reflective systems can have are the cost per inch of aperture and the lack of chromatic and spherical aberration. Reflective systems focus all light to a common point and, having no spherical elements, do not show spherical aberration; but they are all not perfect.

## Newtonian reflectors

In the world of mirrors we can split the discussion into two sub-topics: the Newtonian and the Cassegrain (of all types).

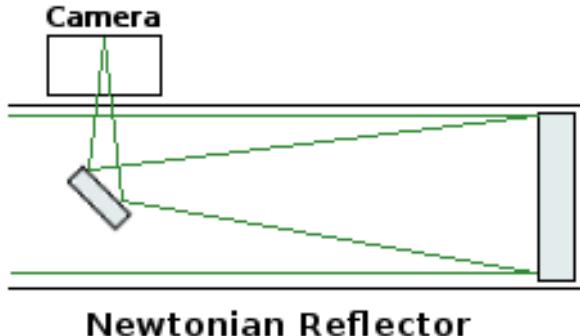


Fig. 19

Newtonian telescopes have been around a long time (Sir Isaac invented them) and generally consist of a parabolic primary mirror which reflects light up to an angled flat mirror which then directs it out of the side of the tube. These are very simple and yet very efficient.

Inch for inch of aperture Newtonian telescopes are generally the cheapest of any of the telescopes on the market today. Optical tubes of 8" of aperture only run a few hundred dollars and specialty astrographic Newtonians can still cost less than \$500.

With no spherical elements the proper Newtonian reflector's worst attribute is that it does display an off-axis aberration known as coma. This is due to its parabolic primary mirror and makes the stars towards the edge of the field look like little seagulls instead of pinpoints. The effect starts close to the optical centre and worsens the closer one gets to the edge of the field. The use of an additional lens called a coma corrector will correct this. The faster the optical system the more prevalent coma is. As most Newtonians work in the range of f/4 to f/6 range all will need some correction. Most coma correctors only work down to f/4 while some specialized scopes work as fast as f/2.8. These most probably have a coma corrector shipped along with them or built in.

Newtonian reflectors, with their primary mirror at the bottom of a long tube are generally not susceptible to dewing up though they are susceptible to tube-currents. Giving the primary mirror enough time to cool to ambient temperature is necessary. Some telescopes have cooling fans installed to help with this. Some Newtonian reflectors are of an open tube design and in this case the primary mirror may need some anti-dew protection.

## Cassegrain reflectors

Cassegrain reflectors come in several 'flavours' from the classical Cassegrain to the Ritchey-Chretien and Dall-Kirkham. The differences between all of these are just in the type of curve used in the two mirrors that comprise the optical system: a concave primary and a convex secondary. The different curves used in the mirrors are all designed to fix coma or some

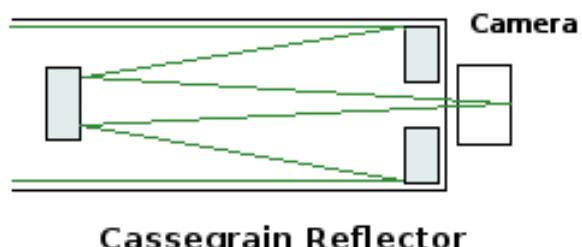


Fig. 20

other aberration such as curvature of field. A design called a Corrected Dall-Kirkham will also have a lens-set in the focuser to help its mirrors along.

All of the Cassegrain telescopes have a hole in the centre of the main mirror. This is to allow the light cone to exit the telescope. Unlike the Newtonian the Cassegrain's secondary mirror does not reflect the light out the side, but back towards the main mirror. All of the various designs allow a long focal length to fit into a compact tube. The hole in the primary mirror has no effect on the image as it is masked by the secondary mirror.

The classical Cassegrain telescope has a parabolic main mirror and an hyperbolic convex secondary mirror (some have elliptical secondaries). The usable field of view is generally fairly small. Classical Cassegrains suffer from coma due to the parabolic primary along with fairly slow focal ratios, generally f/10 and higher.

The Ritchey-Chretien design uses a hyperbolic primary and hyperbolic secondary to reduce the coma inherent in the classical Cassegrain. They display curvature of field but have a large useful field of view. All of the large research telescopes made after the 200 inch Hale telescope are of the Ritchey-Chretien design. They are the favourite of well-funded amateurs and can work well in the f/9 range.

The Dall-Kirkham design has a parabolic primary mirror and a spherical secondary mirror. Coma is greater than the classical Cassegrain so most D-K telescopes operate at f/15 or greater, where the coma is minimized. This makes them rather unsuitable for larger area objects. A newcomer to the field known as the Corrected Dall-Kirkham, such as those offered by Planewave, can work at f/8 or even faster and makes use of a multi-element corrector lens ahead of the focal plane to reduce aberrations and deliver a large field of view.

The rage these days is for Ritchey-Chretien designs which incorporate previously hard to make hyperbolic mirrors. Up until lately R-C telescopes have run in the \$2000/inch aperture range which has priced them out of most people's budgets. But GSO of Taiwan has broken the price barrier offering 6, 8 and 10 inch R-C scopes for as little as \$299. From all reports they are very good. These boast quartz mirrors, carbon-fibre tubes etc. A slightly less expensive version is offered by Orion in steel tubes.

Cassegrain reflectors of any type generally have a 'spider' holding the secondary mirror in place which causes diffraction spikes around bright stars. Those that use a solid tube are generally not susceptible to dewing up though the secondary may need some protection if it is far enough forward in the tube. The primary in Cassegrain telescopes with an open truss design may also need some dew protection.

## Catadioptric reflectors

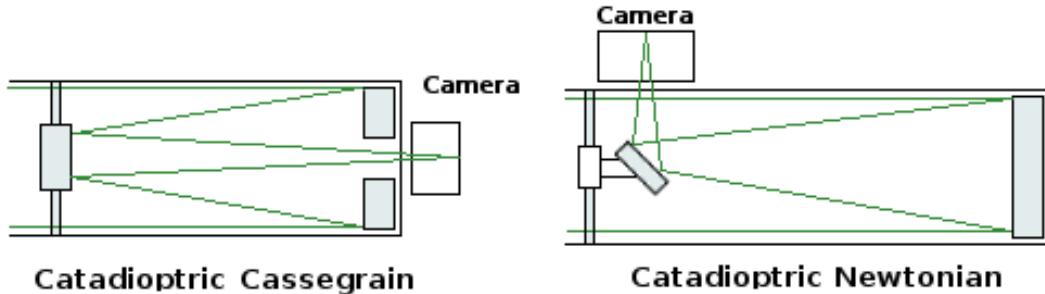


Fig. 21

The last telescope design to discuss is the catadioptric type which are most commonly of the Schmidt-Cassegrain or Maksutov-Cassegrain design. There are some Schmidt and Maksutov Newtonian telescopes available that are very good, they're just not as common. These all incorporate a spherical primary mirror and some form of corrector plate (lens) at the front. The corrector is used to modify the incoming wave-front so as to reduce the spherical aberration caused by the primary mirror.

The Schmidt design uses a thin lens with a complex toroidal curve while the Maksutov uses a thick meniscus lens with spherical curves. Both work very well and like the Cassegrain designs discussed above are very compact. Schmidt-Cassegrains generally operate around f/10 while Maksutov designs work around f/14.

Schmidt-Cassegrain telescopes from Celestron and Meade are probably the most prevalent middle aperture telescopes around. The 'classic' SCT is a compromise; the Schmidt design called for the corrector plate to be at 2 focal lengths from the primary mirror whereas current SCTs have the corrector inside the focal length of the primary.

A new design from Meade known as Advanced Coma Free (ACF) uses a different shaped corrector plate which makes the wavefront leaving the primary think that it was reflected from a hyperbola. That and a hyperbolic secondary caused Meade to originally market them as some form of Ritchey-Chretien which drew bad press from just about everyone.



Fig. 22

Celestron has countered Meade's ACF with its High Definition (HD) systems. These use a built-in correcting lens to flatten the field and reduce coma. The biggest problem with this is that the focal reducer/field flatteners they sell for their standard SCTs (Figure 22) won't work with the new optical designs. Whether the optical system is of the ACF, HD or standard design a focal reducer is almost mandatory with any SCT as operate in the f/10 range and therefore are very slow and have a narrow field of view.

Because of the corrector plate at the front of the tube most catadioptric telescopes require some form of dew control (discussed later).

To offer some advice as to which of all mentioned (and others) is the best optical system to use for imaging would be doing a disservice to a lot of telescope makers. Every optical system has its strengths and weaknesses. Looking for that perfect compromise between enough focal length for planetary imaging and wide enough field for extended nebulae just isn't going to come to pass. In the past the wisdom was that the 8" SCT was the best 'all purpose' telescope but then, there weren't a lot of imagers around. Now, to cover all bases, two or even three optical tubes might be needed.

The best starting point in the search for an imaging telescope is to take the widest field the tube needs to deliver *with a chosen sensor*. This is fairly easy to do with a scientific calculator. The equation for field of view is:

$$2 * \text{Atan}(\text{field}) = .5 * (\text{sensor width/focal length})$$

What is needed is to plug in is the field and the sensor width and get a focal length and to do this the equation is going to have to be worked backwards.

$$\text{focal length} = \text{sensor width/tan( field )}$$

*Take a calculator and enter the desired field in degrees. Then press the TAN key and divide the result by the width of the sensor and press the 1/x key. Out spits a focal length and THAT is the starting point. For example; I have a camera with a 22 mm wide sensor and I want to be able to image a 2 degree field. I open up my hand calculator application and enter:*

<b>Enter 2 then press TAN</b>	=	0.03492076949174772692
<b>Press / and enter 22</b>	=	0.001587307704170351224
<b>then press 1/x</b>	=	629.9975722241433427

*In this example I need a 630 mm scope to deliver the 2 degree field of view I want*

Here is a simple word of wisdom no matter what type of telescope. It's simpler, cheaper and more effective to turn an f/5 optical system into an f/10 system than it is to do the opposite. If it is desired to shoot both extended objects and small stuff like planetary nebulae (or planets) then opt for the faster optical system and a good Barlow to stretch out the focal length, or better yet a TeleVue PowerMate

## Coatings

All modern refractors use 'multi-coated' lenses. The coatings used are materials that have a different refractive index from the substrate of the lens and are used to control or minimize reflection or to enhance reflection; depending on the optical device. Most lens coatings are of the kind that minimize reflection which can cause both a loss of light and unwanted 'ghosts' showing up as light reflects between the components of a multi-lens objective.

The mirrors of reflectors can be coated with one of several grades of aluminum or, for special applications, gold, silver or other metal. Aluminum coatings reflect ~88% of the light that impinges upon them. Enhanced aluminum coatings are formulated to reflect ~92% and the new dielectric coatings on some mirrors can reflect greater than 97%. While this sounds like a large jump remember that imagers collect light over time. With only standard aluminum coatings just take an extra sub-image to make up the few percent lost over enhanced or dielectric.

Normally these days the reflective coating of a mirror is protected by a transparent layer of material such as magnesium fluoride or other formulation which can keep an aluminum coating bright for many years.

## **Tube composition**

Telescope tubes are made from all kinds of things from wood, plastic through steel and carbon fibre. While some makers offer a choice most scopes come with one type of tube and each type has its pros and cons. A quick comparison follows with no attempt to select better or best.

The latest trend in optical tubes seems to be carbon fibre which is thermally stable, lightweight and strong. The trade off with this is that the tubes are generally more expensive, need different lens or mirror cells and (the jury is out) possibly don't transfer heat from anti-dew strips as well as steel or aluminum.

Steel tubes are more stable than aluminum and less expensive though they are heavier. They transfer heat well. Most small refractors sport steel tubes.

Aluminum tubes are as strong as steel but about a third the weight. The transfer heat extremely well.

Open truss telescopes (generally  $\frac{1}{2}$  of a Serrurier truss) are generally seen in larger reflecting telescopes with some offering full Serrurier trusses. These are lightweight, mechanically stiff but complex and expensive.

## Tube baffles

Optical tube baffles, especially in refractors, can cut down greatly on unwanted light getting through to the sensor. Well designed baffles with sharp edges (knife-edge) will cut down on this extra light without adding any sensible reflections of their own. They should be designed and placed so that all of the available light is passed without vignetting.

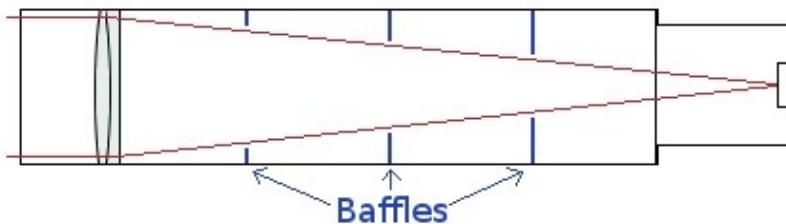


Fig. 23

Some reflectors do carry baffles, mostly from higher-end vendors though plastic baffling systems are showing up in entry-level tubes. Baffled or not, an optical tube should be properly blackened on the inside to minimize reflections.

### So what is this ED glass everyone is touting?

An achromatic double is a lens that has two elements; a front element of crown glass and a rear element of flint glass. Together they reduce the chromatic aberration in an optical system. In the hunt for better lenses Ernst Abbe, an employee in the optical firm of Zeiss discovered that he could reduce chromatic aberration to almost nothing by using a front element made of natural crystals of fluorites. For years that is what high-end (read expensive) objectives used.

Fluorite is fragile, very expensive and not available in large blanks so any fluorite objectives were usually fairly small. Glass makers, always looking for a better way started discovering formulations of glass that could match the dispersive properties of fluorite for less cost and the latest widely used glass for this purpose is the magical FPL-53 which has an Abbe number (measure of dispersion) close to fluorite.

Of course, the glass isn't really magical and won't do a darned thing without the right mating element (the flint element) for it and a good design. But if you are a refractor maker and can't put 'FPL-53' in your press copy somewhere you'll probably go broke.

Do we need FPL-53? No. There are other ED glasses that, mated with a proper flint, will do as well.



*Ryan Fraser shot this wide-angle image of the Coat Hanger asterism from a Purus-Astromechanik tracker with a Canon XT and 50 mm lens.*

## Mounting Rings and Dovetail Bars

All telescopes need some way of being attached to a mount. The most common method for larger scopes is a set of rings while some smaller scopes may come with some form of clamshell. Much larger scopes might use a method of bolting them directly to a plate on the mount.

Rings come in three forms, split rings, solid rings, and rotating rings. The split rings are easy to place on and remove from a telescope as they come apart. One side will have a hinge and the other will have some method of clamping the two halves together. Rings run the whole gamut from very inexpensive to very pricey with just about everything in between.

The rings shown in Figure 24 are a good example of inexpensive split rings. These are available from Orion Telescopes and Binoculars for just about any tube diameter desired. As can be seen, there is a flat on the bottom of each to allow the attachment of a dovetail bar and a flat opposite that can have an accessory bar mounted, or something like a camera piggy-back mount.

Solid rings are usually relegated to holding finder and guide scopes and have some method of adjusting the position of the scope in the rings to align them (see below).



Fig. 25

Clamshell mounts are generally hinged and are made available with many smaller telescopes. The part shown in Figure 26 is from Stellarvue and is



Fig. 24

Rotating rings such as those from Parallax Instruments (Figure 25) are much more complex and therefore much more expensive. These generally have two sets of nested rings, one of which fits the tube and the other which rotates allowing the tube to rotate. To be of any use in astro-photography they must have a fool-proof method of locking in place. Having the rings rotate, even slightly, during a session would ruin the exposures. To put rotating rings on an optical tube usually means removing everything from the tube, installing the rings and then re-installing focusers etc.

26

offered with several of their models. They attach to a mount with a built-in Vixen style dovetail bar which can be seen on the bottom of the clamshell.



Fig. 26

I use three optical tubes (two for imaging and one for guiding) and each has a different style of ring. My two imaging scopes, a refractor and a reflector, both have split rings. One has a heavy machined set and the other has a set somewhat like those from Orion shown above. The guide-scope has a set of solid rings with adjustment.

I've found that even the inexpensive split rings hold my telescope nicely though I would like something heavier some day. The problem with machined rings is that the cost doesn't scale linearly as size goes up. A set of machined rings for the 8" astrograph would not be just double the price of the ones on my 4" refractor.

The solid rings that I use for my guide scope came from Ken's Rings in the US and are quite inexpensive. They come painted instead of anodized, which means that the colour doesn't last long, but then I didn't buy them for beauty. They also don't have a standard dovetail system (which is fine). To put accessory bars that fit the rings on all my tubes just took some scrap aluminum and a bit of machining.

Along with the rings that hold the optical tube will be a dovetail bar of some type to hold the whole thing to a mount. These days there are two types which are generally available for any desired optical tube. These are the Vixen style and the Losmandy style.

The Vixen type of dovetail bar (Figure 27 left side) is 1 and 7/8 inches wide and is held to the rings or (for Schmidt-Cassegrains) screwed to the front and rear cells. Most are of extruded aluminum but some manufacturers (such as Ken's Rings) offer solid machined bars. The Losmandy type shown in Figure 27 (right side) has a cross-section of 3 inches and is held to a tube the same way as the Vixen type.

Is either type of dovetail system any better than the other? I'm sceptical. A piece of metal screwed to another piece of metal doesn't move, whether it's two inches across or three. Now, if I had very large or heavy scopes I'd probably opt for the Losmandy type; for no reason other than they're a closer match to the scope size. Adaptors to mix and match are available from ADM.

Fig. 27





*Jon Gunning shot the heart nebula with a Pentax 100 EDUF astrograph and SBIG ST-10XME camera in hydrogen-alpha. All mounted on an Astro-Physics 1200GTO mount.*

## Electrical Power

Something that can't be ignored when taking up imaging is the need for power. Imaging from a permanent setup has different, and generally simpler, requirements than imaging from a rig that moves around.

The most common (almost ubiquitous) power source that is found in the ranks of imagers in the field is the 12 V automotive battery or some other 12 V source. These can be anything from a small, lightweight piece of equipment such as the Celestron PowerTank, which is really designed for visual observers to power a smaller mount for a nights observing, to a complex, multi-battery setup that only pays lip service to the word 'portable'. To determine what exactly is needed the following questions need to be answered:

**How much current does my equipment draw?**  
**How long do I want to power my equipment?**

The first question is easily answered by the judicious use of a multi-meter or ammeter. To do this first provide some power source for the gear to run off of; either a regulated DC supply plugged into the wall or a battery. Place an ammeter or multi-meter in-line on either positive or negative (with the leads 'pointing' the right way) then setup and plug in your mount with ALL of the equipment that has to be run. Turn it on and read the ammeter. That is the MINIMUM current requirement.

A power source has to have a large enough capacity to be able to power all of the equipment for whatever is the desired number of hours or imaging sessions. Battery capacity is measured in ampere-hours and is the amount of time that a one ampere load can be maintained before the battery voltage drops to a specified point. All batteries have their capacity listed. Let's consider that a night of imaging is eight hours long. If the gear draws 2.5 amperes as measured then a power source that can provide a minimum of 20 amp-hours will be needed. I like a 50% cushion myself so I would use a 33 Ah battery. These as can be purchased at an outlet like Canadian Tire in several forms.

Simple power packs can provide enough power for a telescope and peripherals but if a computer is required in the field then that 33 Ah booster pack won't cut it. In this case a pair of deep-cycle marine or RV batteries connected in parallel may be needed. I generally split my gear between my portable battery, which powers my guider, camera etc., and my car's battery which powers my mount.

Some thought has to be given to how the gear will be connected to the power supply. While most come with the ubiquitous cigarette-type plug these are about the worst connectors in use. They were designed to heat up a lighter, not to hold a connector for a critical imaging session. I prefer banana plugs while some prefer RCA plugs though these were not designed to handle current so be wary of them. Binding posts are the best method, but not as common. Avoid phone style plugs as these short out on plugging or unplugging.

To get the power from the battery pack to your equipment requires wire of the correct gauge. While electrons will flow over any wire when passing current over long distances the gauge of the wire is important. Stay away from coaxial cable as it was not designed for power transmission. Any good two conductor wire of 16 gauge will suffice for long runs while 20 gauge can be used for shorter runs (larger numbers means smaller wire) with lower current.

Wire gauge	Diameter (mm)	Resistance (ohms/km)	Current rating (Amps)
16	.129	13.18	3.700
18	.102	20.95	2.300
20	.081	33.30	1.500
22	.064	52.95	0.920
24	.051	84.22	0.577

As can be seen from the above table a lot of current can't be pushed through a small wire. The current ratings above are very conservative and are sure to be safe. Do keep in mind that the longer the run of wire the more the voltage will drop just by pulling the current through that wire.

Shown in Figure 27 is a (sadly discontinued) Nautilus Marine Booster Pack from Canadian Tire. This is a 33Ah unit that has an absorbed glass mat battery (no spill) that can be 'deep cycled' nicely. It's not overly heavy and provides all of the power that I need for a single night session.

Booster packs such as the Nautilus come with two methods of getting the power out; a cigarette lighter plug and a pair of binding posts. I've found that the cigarette lighter plugs found on these are rather poor quality and as a lot of gear use these types of plugs a triple or even quad plug may be needed.

The second source are heavy-duty binding posts which are designed for booster cables and the like. The Nautilus shown has a rotary switch that allows the binding posts to be turned on and off which is a nice feature. If adding plugs connect them to the binding posts or wire them internally with wire of a proper gauge.

Once power has gotten to the mount it will probably have to go to several places in order to be useful. These might be to power a dew heater, a camera, a USB hub or other devices. Once the power is up to the mount I prefer using RCA plugs to connect things and have a 'power distribution box' to split the 12 V coming in out to my stuff. It also doubles as the 12 V terminus for my anti-dew heaters and I provide RCA



Fig. 27

plugs for 3 heaters and 3 12 V sources. I think that if I was building it anew I would go with 5 or 6 12 V sources.

I don't power my mount through the 12 V distribution box. As I mentioned I usually plug the mount into my car and let the booster pack power everything else. If the car isn't close enough then I'll plug the mount directly into the battery. This means that I'm not using one of the limited number of 12V ports on the distribution box for the mount.



10 amp power supply (#2078)

4.5 amp power supply (#2085)

Fig. 28

power is 'live'. They can short things out.

The Nautilus ships with booster-cables (used once), compressor fittings (used often) and a nice little 'wall-wart' charger that will bring the thing back up to speed in a day which is good when the unit is needed night after night.

In the field remember that things do dew up so if using any AC equipment it's a good plan to cover power supplies etc. to keep them dry and happy.

If in a permanent observatory with mains power all that is needed to drive a lot of DC equipment is a regulated power supply such as provided by Kendrick's Astro Instruments. They offer 4.5 A or 10 A units (Figure 28) and have binding posts and/or a cigarette-type plug on the front. Which one is best depends on the equipment being powered. Calculate the current needed as you would when selecting a battery.

When I am near power I use a Celestron 'regulated' power supply (long on supply, short on regulation) which is specified by them for my CGE mount. I also purchased a 5 A regulated (really this time) power supply from WalMart which was designed to use with a 12 V cooler and modified it with a triple cigarette-lighter plug. This one was very inexpensive and very well designed. AC power

Though I use RCA jacks to connect devices I try not to use pre-built RCA patch cords which are generally made for audio equipment using coaxial cable which, as I mentioned earlier, is not designed for power transmission. Male RCA plugs are cheap and easy to solder to wire. Generally they come with a bit of strain relief and are available in several colours. Watch them though when plugging and unplugging things when the



Fig. 29

supplies are generally protected against over-current but this is not a rule. Read the warning on the next page carefully.

Running AC equipment from a DC source requires an inverter of some form. These can range from very small to very large; large enough to not be portable. The secret is to determine how much power all of your AC gear draws and pick a unit that gives about 100% overhead.

Running a laptop in the field can be problematic as most draw a lot of power; and the power requirements are getting larger as laptops become 'game rated'. Even a low-end laptop can draw enough power to make using it difficult. The 200 W inverter (Figure 29) that I purchased to keep my Celeron M laptop alive in the field does a great job, but it will kill a mini-van battery in about 5 hours. The readout on the inverter told me that the laptop was drawing about 20 W at most times, a value I found a bit hard to believe.

To power a laptop properly would require at least two good automotive batteries connected in parallel (Figure 30). Deep-cycle RV batteries would be a better choice. These would allow enough power to keep things alive through a long imaging session. Deep-cycle batteries can be drawn down and recharged many more times than standard auto batteries.

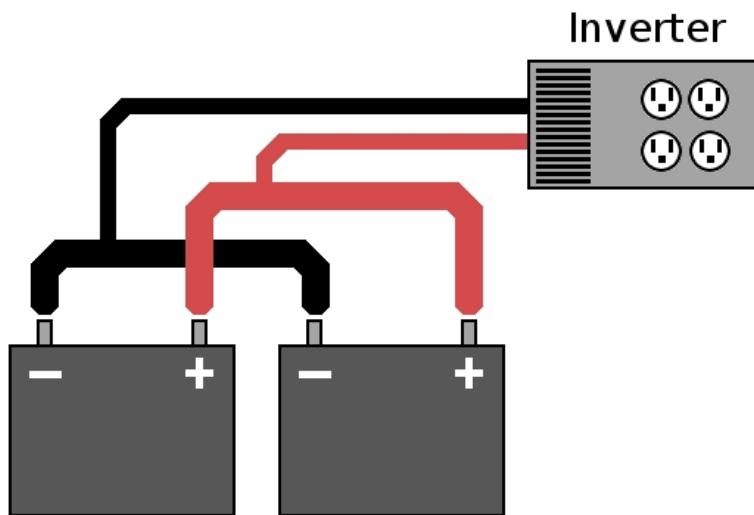


Fig. 30

Keep the battery terminals free of corrosion and clean them periodically; also inspect and replace any frayed or cracked battery terminals. Keeping imaging batteries alive and kicking is much the same as keeping a car's battery in the pink.

Treat batteries well. Always top them up after use and they will be available when needed. When I come back from a session my battery goes on the shelf with the charger plugged in.

Newer batteries such as Gel-cells and absorbed-glass-mat batteries can't spill which makes them a bit safer to use but the cost will be more. Most RV batteries are standard lead-acid batteries. If the battery used isn't maintenance free check the electrolyte periodically.

**Whether in the field or in an observatory equipment needs to be protected. A short in a heat strip or any other piece of equipment can drive a power-supply into shutdown. If a set of batteries are in use with no protection they WILL keep delivering power until something starts to burn, or longer. Make sure that there are fuses on all of the battery's outputs. If using cigarette type connectors use cables with in-line fuses and make sure that they can carry a sufficient load. I suggest fuses rated at 200% of your average load and of a fast-blow design. I have fuses internally in my booster pack and fuses in my cigarette connectors. It is always better to be safe than sorry. And always carry spares of every fuse in use.**



The Andromeda Galaxy imaged by the author using an 80 mm f/6 Nighthawk II achromat from *Stellarvue* and an unmodified Canon XT. The images taken to construct this were not guided.

## Sensors

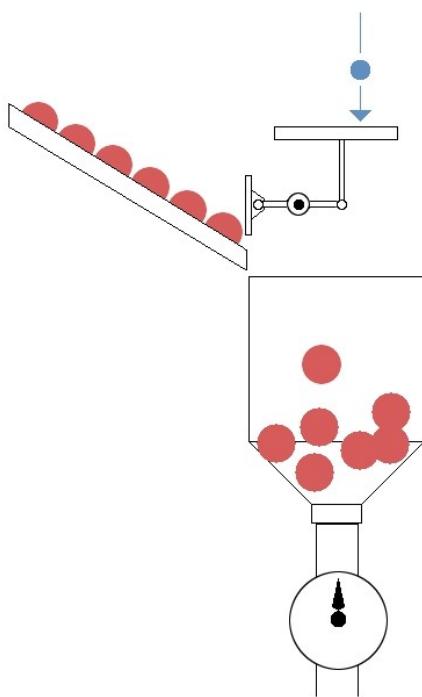


Fig. 31

Digital cameras have completely revolutionized astrophotography. Instead of film an electronic chip containing millions of small pixel elements (pixels) captures and records the photons that are impinging on them.

Without getting into a whole lot of quantum theory how a CCD or CMOS sensor (they're pretty much the same, just the circuitry is different) works is fairly simple. In Figure 31 there are a lineup of electrons (red balls) sitting waiting in a trough. When a photon (blue ball) hits the pixel its energy lifts a gate and lets an electron fall into a bucket. Almost every photon that comes in releases an electron. I say almost because nothing is certain when it comes to very small things banging around. But today's sensors are 80-90% efficient. Compared to the 1 to 5% efficiency of film, it's understandable why digital has taken over astrophotography.

As the exposure continues the photons keep banging into the pixel and electrons keep filling the bucket. At some point in time the bucket is full and, on some CCD chips, the electrons can 'spill' over into the next bucket on either side. The way

that this happens is only in one axis; consider that the buckets each sit in the bottom of a trough. Electrons can spill into the buckets along the trough but not into the next trough.

When the exposure is done the shutter closes and no more photons hit the pixel. Now is time to do a read of the chip and create an image.

Reading the sensor is shown in Figure 32. This is done by unloading each bucket and counting the electrons, actually, measuring the charge.. So in our graphic a valve opens and the electrons fall out of the bottom of the bucket much like passing through a funnel into a tube with a counter which increments one electron at a time. The count is passed onto the camera's brain and all of the numbers are arranged in rows and columns. Where there are no or little electrons in a bucket that will be black, or close to black. Where the buckets are full a high count or white will show up in the image.

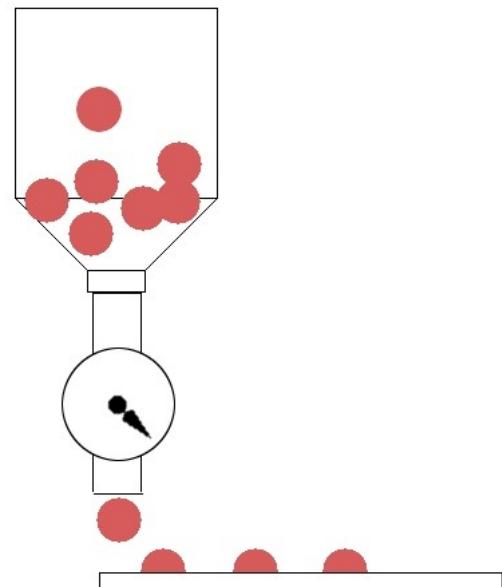


Fig. 32

Of course, this is very simplified but fairly accurate. Instead of a counter the camera reads the charge in each 'well', passes the charge through an analog-digital conversion to get a number and uses that number to create the image.

Sensor chips come in all sizes these days with the largest generally found being the same size as a 35 mm film frame. Most DSLR cameras use a sensor in the APC-C size which is just over half the size of a 35mm frame.

Here is a chart of the various sizes.

Type	Aspect Ratio	Width mm	Height mm	Diagonal mm	Area mm <sup>2</sup>	Relative Area
1/6"	4:3	2.3	1.73	2.88	3.98	1
1/4"	4:3	3.2	2.4	4	7.68	1.93
1/3.6"	4:3	4	3	5	12	3.02
1/3.2"	4:3	4.54	3.42	5.68	15.5	3.89
1/3"	4:3	4.8	3.6	6	17.28	4.34
1/2.7"	4:3	5.27	3.96	6.59	20.87	5.25
1/2"	4:3	6.4	4.8	8	30.72	7.72
1/1.8"	4:3	7.18	5.32	8.93	38.17	9.59
2/3"	4:3	8.8	6.6	11	58.08	14.6
1"	4:3	12.8	9.6	16	122.88	30.88
4/3"	4:3	18	13.5	22.5	243	61.07
APS-C	4:3	25.1	16.7	30.15	419.17	105.35
35mm	4:3	36	24	43.27	864	217.14
645	4:3	56	41.5	69.7	2324	584.07

Each pixel in a sensor is very small, usually in the 5 to 10 micron range. There are those that think big pixels are better and those that think opposite. The argument is that big pixels have a higher signal-to-noise ratio but in my mind, the jury is still out. The state of the art in CCD/CMOS chips is such that all of the current crop are very good.



Fig. 33

I mentioned above in my little description that when a bucket became full the electrons could spill out of their bucket and into the next. This is known as 'blooming' and gives artifacts around bright stars such as shown Figure 33. Most cameras these days contain anti-blooming circuitry that minimizes this effect.

Sensors are chosen by manufacturers depending upon the job that they are expected to do. Smaller sensors generally are used in guide cameras while the larger APC-C and full frame sensors are used in imaging cameras. Each sensor

also has a specification sheet that a manufacturer looks at with possibly the following items (See Nomenclature).

### **Quantum efficiency (QE)**

The percentage of [photons](#) hitting the photo reactive surface that will produce an electron-hole pair (the electron in our bucket).

### **Full Well Capacity**

This is the number of electrons that a pixel can hold before saturating and possibly causing blooming.

### **Gain**

When a CCD is read the pixel charge may be in micro-volts and an amplifier is needed to bring the signal into the range where it is usable. The amount that the signal is increased is the gain. An amplifier not only reads the signal, but reads any noise inherent in the chip which has to be accounted for.

### **Monochrome or colour**

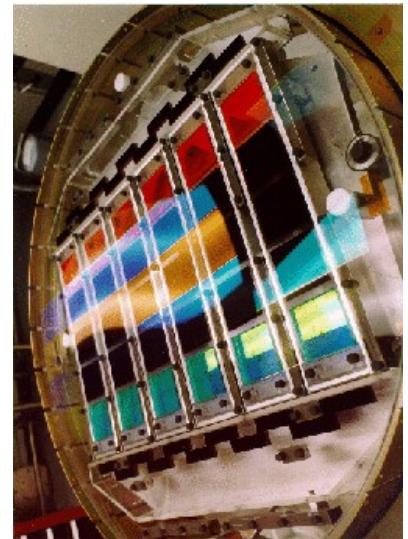
A monochrome chip generally has, millimetre for millimetre, more resolution than a colour sensor. This is due to it being able to register the light of all colours on each pixel whereas a Bayer filter (see the DSLR camera section) splits the light impinging on a colour sensor between red, blue and green pixels.

### **Sensitivity**

Modern sensors are usable to very low light levels and therefore are considered highly sensitive. Many can operate down to near zero lux (lumens/sq. metre).

Sensors can be used in arrays such as that used in the Sloan Digital Sky Survey which is shown in Figure 34. Even though there is a gap between each of the sensors the operators make use of a technique called 'drift-scan' so that images come out seamless. This is a very large array of sensors and along with the optical system that it uses allows it a very large field of view.

Whichever sensor might be found in a camera one can rest assured that the manufacturer has taken into account all of the uses that that camera will be put to during the design phase. More important than the actual sensor (other than physical size) is the circuitry that controls the sensor and creates the image.



*Fig. 34*

## DSLR Cameras

When it comes to deep-sky imaging there are currently two camps. The first group are those that use a DSLR camera like the ones that someone would take on vacation with the family. The other is the 'CCD' crowd that use purpose-built dedicated cameras. I'll discuss the DSLR first.



Any DSLR can be fit to a telescope using an adaptor and a T-ring such as the Lumicon unit shown in Figure 35. This provides the bayonet (or screw) mount such as that found on a standard lens on a telescope. The camera then just 'clicks' onto the telescope as it would to a normal lens.

Many telescopes won't come to proper focus with only a prime-focus adaptor and require some form of extension to be added to the optical train. These are available in many different lengths from vendors such as O'Neil Photo or Astronomics.

*Fig. 35*

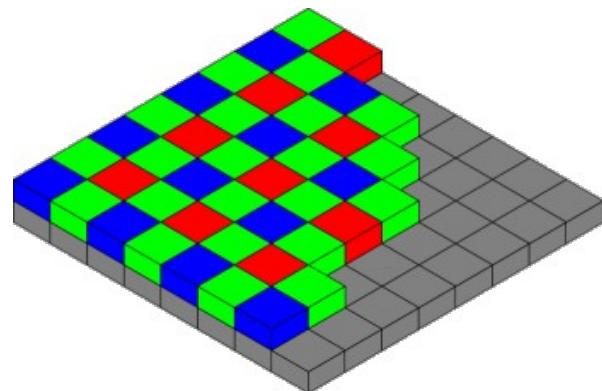
While any DSLR will work for astro-photography by far the most popular are the Canon Digital Rebel series. These are lightweight and

highly capable. One point of interest is that in the past Canon actually offered an 'astro-photography' camera in the form of its model 20Da sadly, no longer available. Canon has offered the greatest support to astro-imagers in the past and I assume that they will continue to do so.

DSLRs are, in the parlance of astro-photographers, single-shot colour cameras. This just means that they take a colour image unlike the monochrome astro-cameras (more later). All of these use something known as a Bayer matrix filter. These filters split the incoming light before it reaches the picture elements (pixels) of the camera's sensor into blue, green and red. Normally, there will be two green elements for each blue and red element as our eyes are mostly green sensitive. A representation of the layout of the pixels is shown in Figure 36.

DSLR imagers generally take a lot of short exposures instead of one long one. The software used to process these first de-Bayer each image so that it can work with the separate channels. Then it 'stacks' them together (adds them) to create the final image set which is then re-combined to provide a colour product.

Most cameras will output their data in some form of 'raw' image which is the data straight from the sensor or in a JPEG image of various sizes that has



*Fig. 36*

been 'massaged' by the camera's processor. While some photographers do use their camera's JPEG output, most work with the raw images.

Other than the hardware needed to mount the camera to the telescope, some method of remotely triggering the camera is a necessity. In the old days this meant a cable or bulb release. These days a remote is generally either infra-red (like a TV remote) or an electronic cable release. I've found that the cable version is the best for me as I can use an intervalometer or computer to run the camera.

I'm not one of the CCD purists and I don't take 'scientific' pictures. I take pretty pictures and therefore can trade less resolution for more ease-of-use. My choice is a Canon Rebel 500D DSLR modified by Hutech to allow access to that deep-red hydrogen-alpha line and I generally run it from the same 12V source that powers everything else in my kit.

The Rebels are nice in that they don't have a lot of weight to counterbalance, are physically small and pack a pile of goodness into the small package. They've become the 'gold standard' for astro-imaging over the past years and I agree with all of the other users that they're the most astro-friendly DSLRs around.

## CMOS vs CCD

There has been quite a discussion over the years as to whether a CMOS sensor or a CCD sensor is better and the answer is, neither. These days either will work just fine and more thought should be given to the camera size and form and the support from the manufacturer or the community for that camera.

## DSLR Power

Camera batteries don't last forever, especially in cool weather so some kind of power-supply is very nice to have. Fortunately, camera power supplies are fairly simple as they just take the 12V from your power source and drop it down into whatever voltage that the camera needs. For my Rebel, I use a simple 7808 linear voltage regulator and a heat-sink, and built them into a small project box. It has an RCA plug to bring 12V in and a 3.5 mm mono phone plug to get the 8v needed out.



Fig. 37

To get the power from your power supply into the camera some form of battery adaptor will be needed. For my Canon XT I used one machined out of plastic but for my modified T1i I went another route. A battery can be 'gutted' to build an adaptor which is what many do; but for my T1i I found an off-shore

company that supplied AC adaptors (the Canon offerings are horrendously expensive for what they do) for about \$35 dollars. I modified it and now I can power my T1i from either mains power or 12V.

For users of Canon cameras the manufacturer ships software with their cameras that can perform most of ones exposure timing needs over the camera USB connection.

Most DSLRs these days have a fairly good LCD screen on the back which can make focusing and framing much simpler than looking through the viewfinder. The problem with either the screen or viewfinder is that it helps to be a contortionist to look at them in some orientations of the telescope. To ease aching necks and backs there are two options available to most DSLR owners;to purchase a 90 degree magnifying viewer for the camera or to use a netbook or laptop computer.



Fig. 38

The Nikon DR-6 (Figure 38) is very good. It allows a 2x magnification of the camera viewfinder which may be enough to reach good focus.

Better is to use a computer. This can be at the telescope with a netbook or laptop or a desktop computer if working from the warm-room with a remote focuser. If the camera has a live-view mode this is the best way to go as it can be used with a focusing mask (later) or other aid at very high magnification.

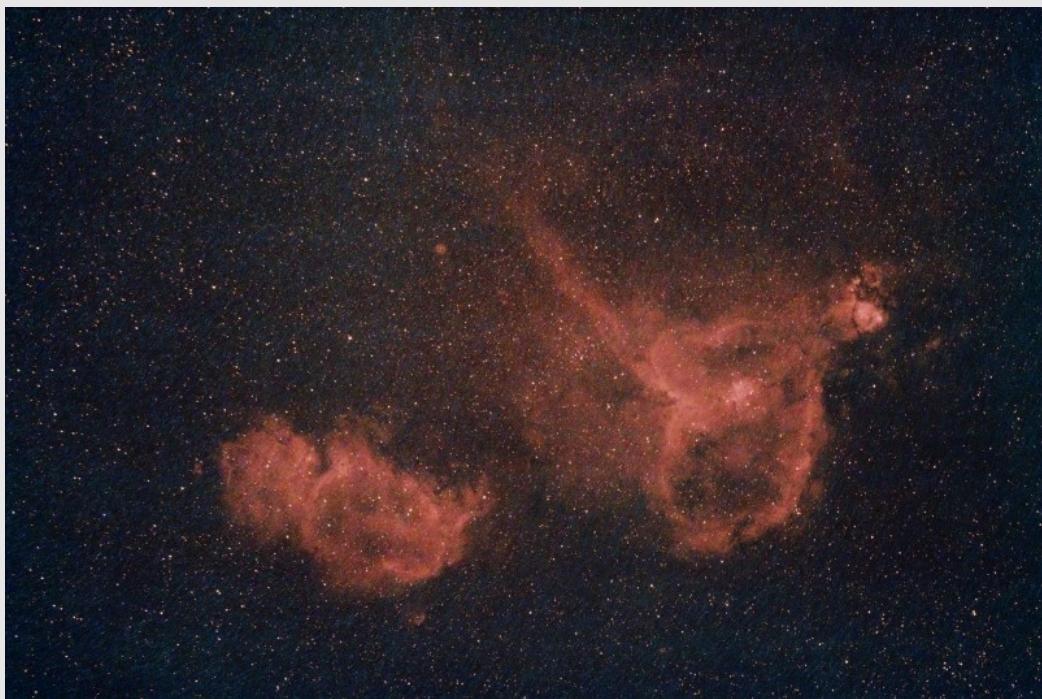
Live-view modes on DSLR cameras use up a lot of battery so it is best to power the camera from an AC-DC adaptor (wall-wart) or from some form of DC-DC converter (Appendix III)

## What are these modified DSLR cameras I hear about?

All of the DSLR cameras on the market ship from the manufacturer with an ultra-violet/infra-red cut filter of some kind. These allow only light in the visual wavelengths to pass to the sensor which is fine when taking pictures of a mountain or little Sally's birthday party.

Just below the visual band at a wavelength of 652nm is the hydrogen-alpha (or Balmer-alpha) emission line. The photons of this band are emitted by an electron dropping from the 3<sup>rd</sup> 'orbit' to the 2<sup>nd</sup> 'orbit' in a neutral hydrogen atom. Many nebulae are rich in hydrogen which means that they radiate strongly in this light.

Modifying a DSLR consists of removing the stock UV/IR filter and replacing it with one that will allow the 652nm wavelength light of hydrogen alpha to pass. The sensors themselves can 'see' the light. Below is an image of a hydrogen-rich nebula taken with a modified DSLR and Hydrogen alpha filter.



*This is an image of the Heart and Soul nebulae (IC1805 and IC1848) taken in hydrogen alpha light on my modified Canon DSLR.*

## CCD Cameras

CCD imagers have gone a different route than the DSLR crowd by using a dedicated astro-camera to ply their vocation. These cameras are designed specifically for use on a telescope and some of them sport some type of research grade sensors.

While some single-shot colour cameras are available most people use cameras that output monochrome only which means that the imager takes four images in order to get a colour picture. This is knowns as LRGB imaging and stands for Luminosity, Red, Green, Blue. The advantage of this method is that higher-resolution images are available (sometimes) along with more vibrant colour as the sensors tend to be a lot more sensitive than those used in DLSR cameras. Also, there is no Bayer filters or UV/IR cut filters getting in the way of the light.

These cameras tend to be quite expensive and require the use of a computer in order to function. They also tend to draw a lot of current which means that they are best used in a permanent setup in an observatory. While some people do take them 'on the road' a lot of care has to be taken in designing a 'power plant' to keep everything running.

One of the big names in the CCD market is Santa Barbara Instruments Group (SBIG) which makes the 8300M camera shown in figure 39. SBIG is nowhere near the only provider with cameras starting to show up from many new manufacturers as the availability of adequate sensors increases and the prices of the parts drops.



Fig. 40



**SBIG ST-8300M Camera**

Fig. 39

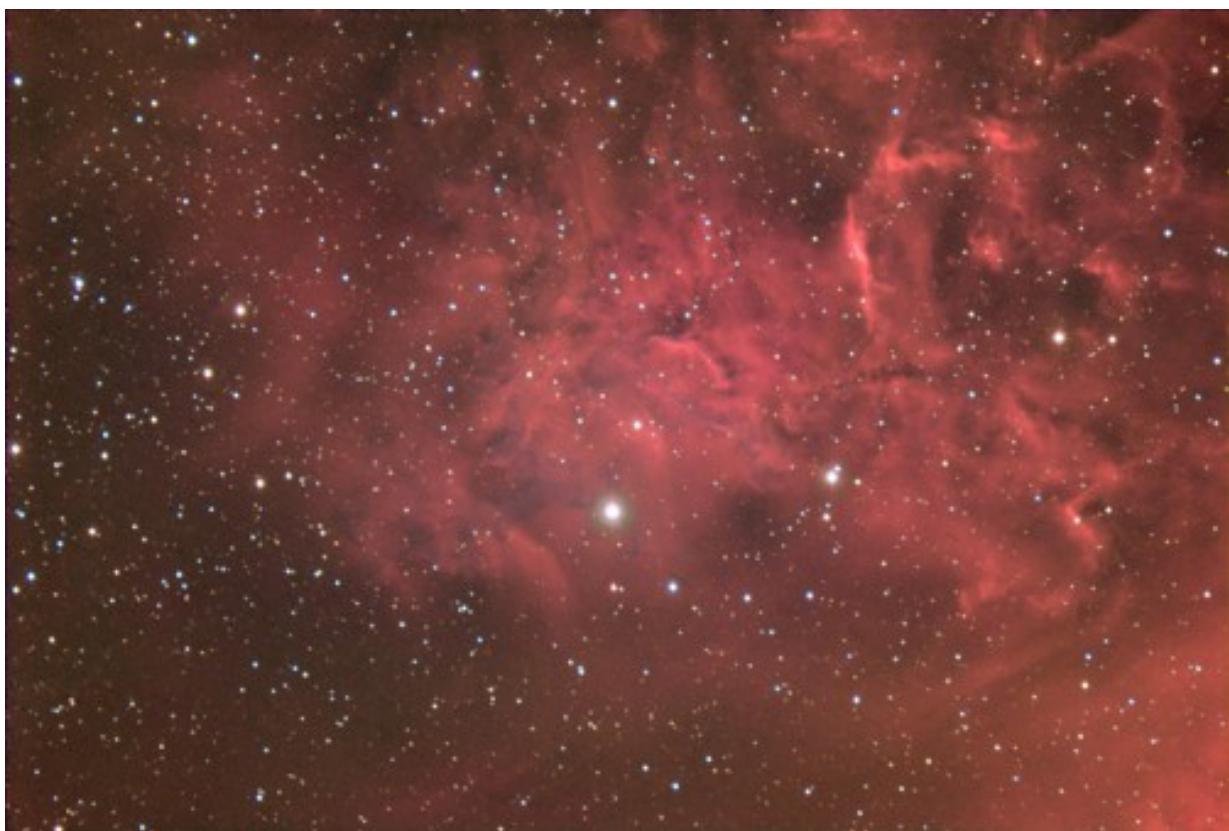
In order to take the separate colour images a filter wheel and filters are required. These devices fit between the telescope and the camera and have a rotating filter holder that can move a new filter into place in front of the sensor as needed. Some are powered and are controllable from a computer and some have to be operated manually.

The newer cameras all use USB connections to connect to the computers that control them and store the images that they take.

These cameras almost all allow 'binning'. This means that a matrix of 2x2, 3x3 etc pixels can be treated as a single pixel. A normal methodology is to shoot the luminance channel at full resolution and shoot the three colour channels binned. The full resolution is not needed in the colour channels and the camera can record the colour quicker binned.

Most of the cameras are also thermo-electrically cooled, many with the cooling controllable. Keeping the sensor cool keeps a lot of thermal noise from building up and makes the job of the dark frames a lot simpler.

CCD cameras come in many shapes and sizes, from those not much larger than a 2" eyepiece such as some of the QHY models or the Loadstar guider right up to lunch box-sized units like the SBIG 11000 series. How much camera can be counterbalanced is sometimes the main parameter in choice. All of the cameras on the market these days do a good job and some are close to the price of a modified DSLR.



*Bill Gardner shot IC405 in HaRGB with an Astro-Physics 155 refractor and SBIG ST-10XME camera mounted on an Astro-Physics AP900GTO mount.*

## Astro-photography With Camera Lenses



Fig. 41

For large sweeps of sky or for imaging very extended objects the telescope and astro-graph can be eschewed in favour of a camera lens. Wide angle or telephoto, they all fit into the spectrum of optics what can be used effectively to image the night sky.

Camera lenses, in the most cases, have to be treated much the same as their longer brethren when it comes to deep-sky object imaging. While shots of constellations can be taken from a static camera tripod with shots of less than around 15 seconds, any longer exposures should be taken from an equatorial platform of some sort and long exposures or long telephoto shots should be guided.

Imaging with the family camera can be very satisfying. Large scale objects such as bright comets, star clouds and extended nebulae are easily captured with short focal length lenses while the grist for longer telephoto lenses runs from the moon to the nearer galaxies and bright nebulae.

With a camera on a tripod the stars will start to trail immediately after the shutter is opened. Just how long an exposure can last without severe trailing depends on the focal length of the lens and the size of pixels on the sensor. First determine the field of view and arcseconds per pixel:

$$\begin{aligned} FOV = & \quad 2\arctan(0.5w/f) \\ \text{arcsec/pixel} = & \quad FOV/\text{number of pixels across} * 3600 \end{aligned}$$

For a Canon 500D and a 50 mm lens the field of view would be:  $\arctan((22.3/50) * .5) * 2$  or 25.142 degrees. Next determine the arcsec/pixel. The 500D's sensor is 4770 usable pixels across. Dividing the 25.142 degrees by 4770 then multiplying by 3600 (arcseconds in a degree) returns 18.9 arcsec/pixel. The stars move past at 15 arcseconds per second so this combination will show no trailing in a 1 second exposure and in a 15 second exposure the stars will trail 12 pixels. As the FOV scales linearly this can be extrapolated to a 100 mm lens which would have stars trailing 24 pixels and a 200mm lens where they would trail 48 pixels. To determine what is and what isn't acceptable only shooting will tell.

Camera lenses, especially those designed for consumer use are generally not the greatest optical components built and most display a lot of softness when the aperture is wide open. A consumer 'kit lens' such as the 18-55 mm zoom that Canon ships with their cameras has a focal ratio range of f/3.5 to f/5.6. These lenses should be shot in manual mode with the aperture set to f/5.6 at 18 mm or f/8 at 55mm. Stopping down the lenses masks off the worst part of the lens making the image much sharper. Of course, exposures will lengthen.

## Camera mountings

Pleasing images can be shot from a standard photographic tripod as long as exposures are kept below the point that trailing gets out of hand. Exposures can't be long enough to register much in the way of nebular or star colour or much in the way of the star clouds of the Milky Way.

The next step up from a tripod is to use a barn-door tracker. These are small devices, generally made out of wood, that will track the earth's rotation for short periods. Some are turned by hand and some have had motors attached. The example in Figure 42, built by Chris L. Peterson of Colorado, is fairly representative. Note that this is motor driven. The camera is held by a small ball-head that is attached to the tracker allowing it to point to any section of the sky. Instructions on how to build these are easily found on the web.

These work by having the hinge(s) pointed at the celestial pole. Then by turning a threaded rod the 'barn door' opens which properly allows the camera to track the night sky as the earth turns. A simple unit comprised of two boards with a hinge will allow shorter exposures but the more complex units with two or three boards reduce the tracking errors to very low levels.



Fig. 42

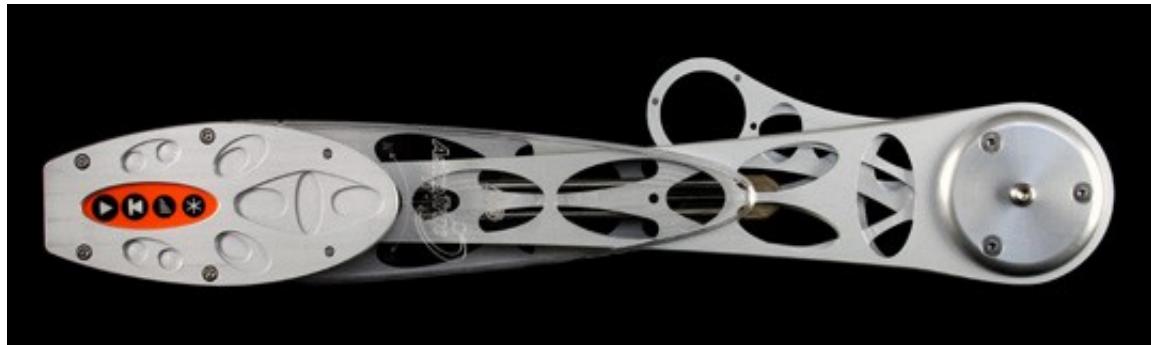


Fig. 43

Better than a barn-door tracker is a purpose-built tracking device such as the Kenko SkyMemo or the Astrotrac (figure 43). These attach to a camera tripod and, when properly polar aligned can track to a high degree of accuracy. Either the SkyMemo or the Astrotrac are able to very accurately keep a camera tracking for quite long exposures, but there is no method available to do any guiding of the images.

The last method and the best of course for wide angle imaging is to mount the camera and its lens on a telescope mount and shoot the images just as if imaging with the main telescope. This necessitates having some method of attaching a camera to the telescope or mount.

Celestron and Meade each offer a 'piggy-back' adaptor that screws to their telescope tubes and allows the attachment of a camera using the standard 1/4-20 screw on the bottom. Third party vendors such as Losmandy and ADM offer a full line of piggy-back adaptors that can be used on just about any mount. These allow you to shoot wide angle using your normal astro-photography equipment. Piggy-back adaptors can be simple brackets such as the Meade unit in Figure 44 or can be 2-axis or even 3-axis adaptors that allow the telescope and camera to point in completely different directions.

Once the camera is powered and pointed there has to be some method of tripping the shutter. Many DSLRs have the provision to have a remote shutter release attached. These can either be simple push-and-lock remotes or have some intelligence and act as an intervalometer, a device that allows a sequence of exposures to be programmed and automatically shot.

A good intervalometer, such as the TOGA Intervalometer, allow the use of mirror lock-up; a function of the camera that flips the mirror up and then waits a set amount of time before opening the shutter. This allows any vibration from the heavy mirror raising to settle down before the shutter is opened. If there is no mirror lock-up (MLU) on a camera then the 'hat trick' can be used. A hat is held over the end of the lens and the shutter is tripped. After a few seconds, when the vibration has settled, the hat is removed and the exposure starts.

### **Wide Angle Imaging**

Arbitrarily I've split the spectrum of focal lengths of camera lenses into three groups. The first is the wide angle group, those lenses of less than 100 mm focal length. In the middle of this group is the old standard lens, the 50 mm, a most versatile lens.

The normal wide angle lens that is offered by most camera manufacturers is the 28mm, which is also the bottom end of many zoom lenses that are offered. A good 28mm lens is a wonderful wide field lens that offers the ability to image sweeping vistas of the heavens, especially useful along the Milky Way.

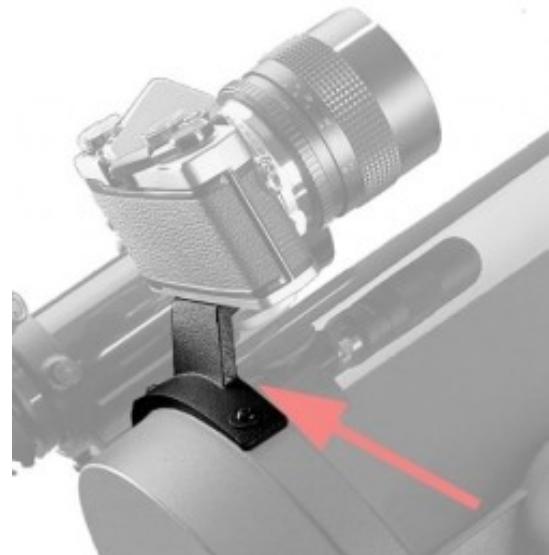


Fig. 44

## Medium Telephoto Imaging

Lenses with focal lengths from 100 to 200 mm fall into my category of medium field. One of the most useful of lenses, the Nikkor 180 mm ED f/2.8 falls into this range and should be in every imager's kit if it will fit their camera. Nikkor lenses will fit onto Canon Rebel bodies with an inexpensive adaptor.

The 180ED incorporates an element of extra-low dispersion glass that allows it to deliver pinpoint star images with the aperture set wide open at f/2.8. This lens works out to a very fast 70mm refractor with 5 elements to keep aberrations in check. A manual focus version can be found on the used market for a few hundred dollars.

A medium or long telephoto lens can put a lot of stress on the attachment ring on the camera. When being hand-held this is no problem as the lens is supported. On a piggy-back adaptor the camera itself is being held and the heavy lens is suspended out front. Some manufacturers offer collars that go around the lens and attach to a tripod (or piggy-back adaptor). Guide-scope rings can be used if care is taken while tightening them to not change focus as the rings may have to clamp on the focus collar.

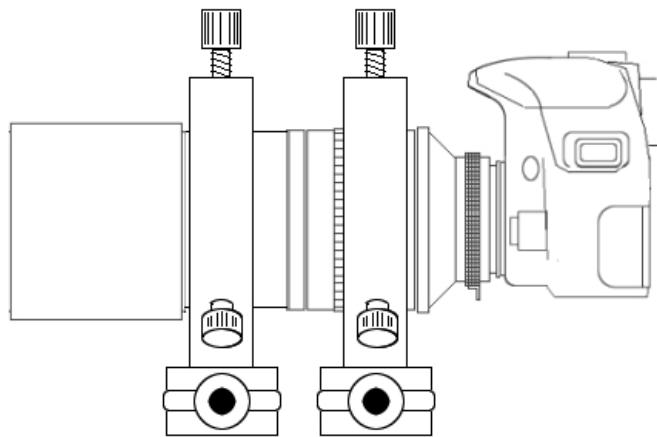


Fig. 45

telescopes and perform as well. These long lenses require guiding or at least well polar-aligned tracking.

## Long Telephoto images

Above 200 mm the lenses fall into the long telephoto category. Good specimens of these lenses are very expensive, more expensive than most telescopes in the short apochromatic telescope category. They do though offer a wider field than most



*Dan Williams shot this wide-angle of the Andromeda Galaxy from a tripod using a Canon DSLR and 70-200 f/2.8 zoom set to 195 mm. Four seconds at ISO2500*

## Auto-Guiders

While some people may enjoy staring at a reticule for hours, most imagers these days make use of some form of auto-guiding when plying their avocation. Since the first commercial auto-guider hit the market in the form of the SBIG ST-4, staring at a reticule became a thing of the past. With the advent of small and efficient portable computers and small, sensitive cameras, auto-guiding is available now to just about anyone. With so many people starting to take images through their telescope the stand-alone guider (no computer) has even made a resurgence.

Auto-guiders these days fall into three distinct categories. Those that don't need a computer, those that do need a computer and those than only need a computer to configure them. Those may sound like odd categories but they describe well the way things are.

For many years the only stand-alone auto-guider was the SBIG ST-4. These were discontinued in about 2002 due to lack of components but very many are still being used by imagers. They run from a 12 V source and don't need any external computer to operate. This was the situation until a few years ago when the Orion Solitaire started shipping (out of stock as of this writing) at around \$500. In 2010 Celestron and SkyWatcher jumped into the market with the NexGuide/SynGuide products, stand-alone guiders that also run off of 12 V for about \$300 (Figure 46).

In the category of those auto-guiders that need a computer only some of the time is the SBIG SG-4, a descendant of SBIG's original guider. These need a computer to be configured, but once that is done they can run on their own.

The last category are the guiders which need a computer. These are generally software based and use anything from a simple webcam to a dedicated guide camera to operate. The camera only captures the images which software on the computer then processes. A list of popular software guiding packages are shown below. All are free for download.



Fig. 46

Guide Dog	<a href="http://www.barkosoftware.com/GuideDog/">www.barkosoftware.com/GuideDog/</a>
GuideMaster	<a href="http://www.guidemaster.de/index_en.asp">www.guidemaster.de/index_en.asp</a>
MetaGuide	<a href="http://www.astrogEEKS.com/Bliss/MetaGuide">www.astrogEEKS.com/Bliss/MetaGuide</a>
PHD Guiding	<a href="http://www.stark-labs.com/phdguiding.html">www.stark-labs.com/phdguiding.html</a>



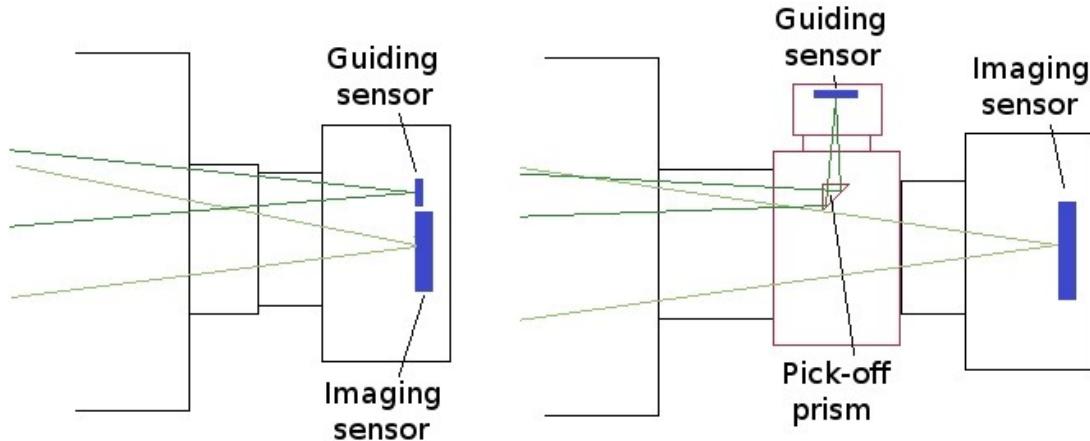
*Fig. 47*

In order to interface the computer to the mount's auto-guide port something like the TOGA LX-Guider/Focuser or the Shoestring Astronomy GPUSB unit will be needed. Both of these work with the standard ST-4 auto-guide port that is offered on most mounts. Both can also make use of a feature called 'pulse-guiding' that provides a more accurate timing source than the software timers.

The next part of the guider system is the guide-scope, or alternatively an Off-axis-guider (OAG). A guide-scope is usually a small aperture refractor that rides on the mount above or beside the main imaging scope and to which the guide-camera is attached. This is usually adjustable in two axes by riding in a pair of over-sized rings with screws spaced every 120 degrees. This is a tried-and-true system but was, I'm afraid, invented by a sadistic astronomer. This method is nowhere near the easiest way to find and centre a guide-star and Orion has offered an X-Y Guide-star Finder which allows the use of only two adjustment screws (up/down and left/right) to centre the chosen guide-star.

My guide-scope is mounted the old fashioned way with two rings and spaced thumbscrews. I purchased the system from Ken's Rings of Louisiana.

An alternative, and relative newcomer to the guide-scope market is the finder-based guider one of which is offered by KW Telescope as the KwikGuider. This mates a high-quality guide camera from QHY to a simple achromatic finder. There are no adjustments needed as the field of view is so great, and the sensor so large that there is always a star somewhere in the field that the software (usually PHD



*Fig. 48*

Guider) can find. This lightweight and sturdy unit fits into the standard finder dovetail found on most mounts.

The problem with all separate imaging/guiding scope setups is 'differential flexure' (see the section on this subject). This problem manifests itself when the imaging and guide-scopes don't remain in perfect orientation. There are two solutions to this. The first is to use an off-axis guider (Figure 48, right). This rides between the imaging telescope and the camera and has a pick-off prism that projects into the light path and redirects a star image up to the guide-camera. The second is to use a dual-chip camera (Figure 48, left) such as those that SBIG offers. These have a large imaging sensor and a small guiding sensor in the same focal plane. Both the OAG and dual-chip setups eradicate differential flexure but limit the choice of guide-stars.

If a separate guide-scope is being used along with a stand-alone guider then there is no more useful accessory than a flip-mirror. These mount between the telescope and the guide-camera and have a mirror that can be flipped out of the way to image, or into the light path to direct the output of the telescope up to a reticule eyepiece (eyepiece with cross-hairs). When a star is in the cross hairs it is on the sensor of the guide-camera, and in focus.

Reticule eyepieces are regular type eyepieces with an internal reticule that may be illuminated or not. Many different types can be purchased with some more complex than others. For guide-star acquisition the best type would be either a simple cross-hair or perhaps the more common dual cross-hair.

A guide-scope has to have some way of being mounted to the imaging scope, or mount. Some people like to have their two optical tubes 'stacked' and others like them side-by-side. I'll use either depending on the mount I'm using but I prefer the side-by-side method. Side-by-side plates for any mount dovetail can be had from ADM or Losmandy.

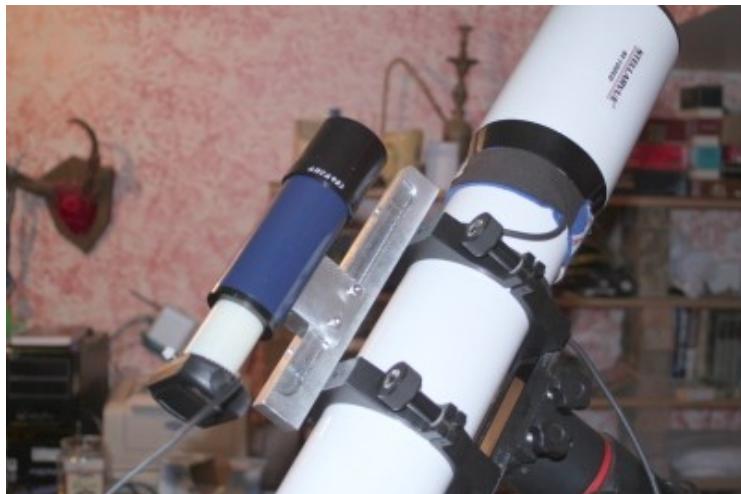


Fig. 50



Fig. 49

Guide-scopes don't have to be all that fancy. Just about anything with a lens that will form an image can be put to use. Good finder scopes can be modified nicely to guide an image using a simple web-cam or 'solar system imager'. Figure 50 shows a 'baby-guider' that I put together using a good quality Antares 7x50 finder and a Celestron NexImage camera.

I'm not a fan of the off-axis-guider and therefore always use a separate guide-scope to keep things pointed correctly. I

opted for a Stellarvue Nighthawk II (now discontinued) 80 mm f/6 achromat. It's just about the best guide-scope around being light, solid and having great optics.

I either guide using a venerable ST-4 auto guider (above), or I use a Celestron NexImage camera and a TOGA LX Guider/Focuser and a laptop or netbook. Both will keep things pointed well enough to deliver round stars from images up to 10 minutes long with the CGE.

With the Nighthawk and ST-4 I use a Meade 644 flip-mirror (Figure 51) with a custom-made tail piece that my best friend, David Rubenhagen, machined up for me. This was necessary as I bought the thing used and it didn't come with any of the spacers that ship with them from the factory. The machined part is stiffer than the spacers..

With all of the new self-contained guiders coming on the market these days why keep using an old ST-4? The answer is simple in that it works well and I already own one. Would I recommend a used ST-4 over any of the Orions, Celestrons or SBIGs currently shipping? You bet. The technology is bullet-proof and the outcome is phenomenal. If my ST-4 ever dies I'll look for another used one on Astromart or somewhere else.

As I mentioned, I don't use the ST-4 all the time. If I'm in a place where I can use a computer I have no problem swapping the ST-4 out for the Celestron NexImage /TOGA LX Guider/Focuser pair. The CCD-based NexImage is sensitive enough to guide on a 9<sup>th</sup> magnitude star with the 80 mm f/6 scope and can be used with either TOGA's software or the stellar MetaGuide video-based guiding software from Astrogeeks.com.

As mentioned previously my guide-scope normally rides on a side-by-side plate with either the SV102ED or the AT8IN scope but it can ride piggy-back on either. I've found that the side-saddle approach is best for me as I don't have much in the way of flexure problems and it is easier to reach the reticule eyepiece in most orientations. My side-by-side (SBS) unit is home-made, heavy and doesn't flex AT ALL. It also allows me a lot of versatility in mountings. The imaging telescopes use Vixen style dovetails while the guide-scope uses a Ken's Rings style. The SBS uses both of these while mating to the Losmandy carrier on the CGE. It sounds complicated but there are reasons for putting it together this way.

Another benefit to the side-by-side unit is that it allows me to over-balance my whole setup in declination very simply. Similar to balancing the mount in RA east-heavy, having the dec axis off balance is a good way to fight backlash.



Fig. 51

So, how do auto-guiders work? Well, no matter what type of setup they all work basically the same way and the work-flow looks something like this:

- **Acquire guide star**
- **Focus**
- **Calibrate**
- **Track**

Acquiring the guide star can be as simple clicking on one on a computer display, or looking at the readout or some other indicator on a stand-alone auto-guider. Some guiders will automatically select a guide-star from any stars in the field while others allow one to pick and choose.

Once a suitable star is found the guide-scope should be focused. Oddly, the old ST-4 seems to prefer a slightly de-focused star in some cases; but generally a well-focused star image is to be preferred.

Calibration consists of the guider moving the mount N/S and E/W in a cross or L pattern to determine how much the chosen guide-star moves in a specified amount of time. Some guiders can be configured to take into account any backlash but it's always a good idea to use the anti-backlash settings on your mount to minimize this. Once the calibration is done the system stores an image to use as its reference, then takes more images spaced as desired and compares them with the stored reference. If the star has moved on the sensor the auto-guider will nudge the scope to bring it back into position. Good guiders can guide to around  $\frac{1}{4}$  to 1/5 of a pixel.

Always try to pick a guide-star that is in the field of the imaging camera. The farther away from the target a guide-star is the more field rotation can show up. This manifests just like a non-aligned mount and rotates the field around the guide-star.



*Pete Raine shot this image of M1 using an AstroTech 8" Ritchey-Chretien on a Celestron CGE mount. Shot with a Canon XT and Lumicon Deep Sky Filter.*

## Focusers

Three basic types of focusers are common on astro-graphs: the helical, the Crayford and the rack-and-pinion. All perform the same basic function of moving a camera along the optical axis to bring the sensor to the focal plane.

Rack-and-pinion focusers use an in-line gearing system to move the focuser's draw tube in and out. Cheaper units are generally poorly built and display a lot of backlash among other problems. These should be avoided. Good R&P focusers, such as those offered on Takahashi telescopes are a dream to use and are better than many low-end Crayford types. They are also generally better at holding a large camera than the Crayford designs.

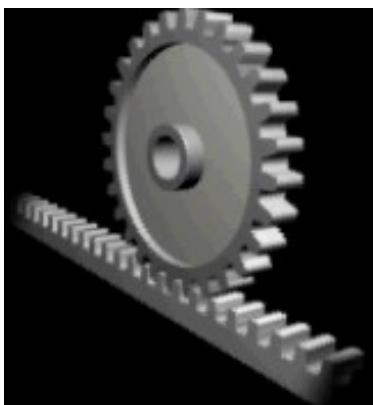


Fig. 52

Instead of a gearing system Crayford focusers use the friction of a rotating steel bar running against a 'flat' machined into the draw tube (Figure 53) to move the draw tube in and out. The draw tube is kept in position by (usually) four small ball bearings opposite the focusing bar. Crayfords are adjusted by either putting tension on the focusing bar or by putting tension on the draw tube. The latter is not a good system as it can 'cock' the draw tube pushing the camera out of square with the optical path.

Crayford focusers have become the de-facto standard as almost all optical tube companies put them on their offerings. Units made by Moonlight, Starlight Instruments, JMI and others are all very well built and are offered as either standard equipment or premium options on

many telescopes. The king of focusers in my opinion is the Feather Touch line which use a twist on the standard Crayford focuser called the 'reverse Crayford'. These are a joy to use being silky smooth in operation and able to hold a good load without slipping.

Helical focusers are wonderful units that will hold a *lot* of weight and adjust for focus beautifully. They have two main problems: first that the instrument rotates while focusing and second that they are very difficult to motorize.

Most focusers come with some form of brass compression ring in them where the camera adaptor is inserted. These might be fine for eyepieces and were first offered so that the thumbscrews don't mar an eyepiece's barrel. For imaging they are not very good as they tend not to hold the camera very tightly and it can 'cock over' putting it out of alignment (see the section on Fighting Flexure). A much more useful system would be for the focuser to have two tightening thumbscrews 120 degrees apart

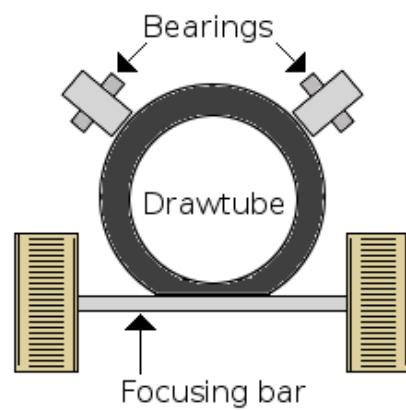


Fig. 53

and no compression ring. FeatherTouch focusers have both two screws and a compression ring and I've had no problem with mine.

Another thing that can throw your camera out of square is the focus locking method used by the manufacturer. Most makers lock their focusers by tightening a thumbscrew thereby adding pressure to the draw tube. This can tilt the tube out of square. Look for a focuser that can be tensioned enough to hold your camera without having to be locked or, better yet, a focuser where the brake (lock) acts on the rotating bar and not against the draw tube.

Whichever type of focuser is chosen the only really important thing to look for is that it holds the load to be used securely and square to the optical path. Anything else is just luxury.

Continuing on the subject of focusing and focusers I am of the mind that no imaging telescope should be without a powered focuser, especially if a laptop or other computer is available at the telescope.



*Fig. 54*  
Power can be added to just about any focuser. JMI offers 'MOTOFocus' units such as the one shown in Figure 54 for just about any make and model of focuser on the market, and for a very good price. These units are well thought out and very useful. An added bonus is that they are simple to convert to computer control. I have one on the FeatherTouch focuser my Stellarvue refractor is equipped with and I love it.

Powered focusers are offered by companies like JMI and can be units with simple DC motors that just turn the focuser in and out or more complex devices with stepper motors, temperature compensating circuitry and other fancy stuff. Some units can also do auto-focusing with suitable computer software.

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For those that are on a budget devices like the TOGA LX-Guider/Focuser can be very useful. These are able to control two DC powered focusers from a computer. Using the live view built into a DSLR and the TOGA webcam window showing the output of a guide-scope, an imager can make sure that both scopes are properly focused all the time.

All of my optical tubes carry Crayford focusers. Two of them are the standard inexpensive units that shipped with the scopes and one (my Stellarvue SV102ED) carries an optional FeatherTouch unit.

All of them do the job they have to do quite nicely. The AstroTech (GSO) focuser on my 8" f/4 is not perfect, but it holds my DSLR nicely without focus lock and that's all I ask of it. Both the AstroTech focuser and the FeatherTouch are powered; the refractor with a JMI MOTOFocus unit and the reflector with a home-brew motor (see the DIY section).

The JMI MOTOFocus utilizes a very tiny gear head DC motor that screws to a ring that fits onto the FeatherTouch focuser just inside the coarse focus knob. The motor drives the fine focus knob via a

rubber O-ring on a pulley that makes contact with the knob. Not the best system but it works. With the MOTOFocus in place manual focusing is only available using fine focus.

The JMI controller is interesting. It has three basic speeds but when set to either of the slower speeds holding down a button for over 2 seconds kicks the focuser into high. This can be disconcerting at times but it appears to work. A 9 V battery drives the whole thing.

## **Two focusing methods**

Using computers and good focus aids acquiring that perfect focus is no longer a black art. I image with a DSLR so one of the two methods that I'll discuss will be DSLR-ish while the other can be used by anyone that has a computer handy.

Using the camera's LiveView and a netbook computer has made life very simple. I slew to a bright star near my target and place a Bahtinov mask (see section on focusing masks) on the telescope. With the Canon and TOGA software running I can adjust focus to perfection using the netbook to display the output from the camera.

A modification of the first method is for those cameras with no live video. Setup just as in the previous paragraph. Next shoot a 10 second exposure and with the image on the camera's LCD (or computer screen) zoom in and look at the state of the focus which can then be adjusted if necessary. Repeat as needed. It takes a bit of time but focus will be achieved.



*The author shot the Pleiades with an unmodified Canon 350D and Stellarvue  
SV102ED mounted on a Celestron CGE.*

## Focusing Masks

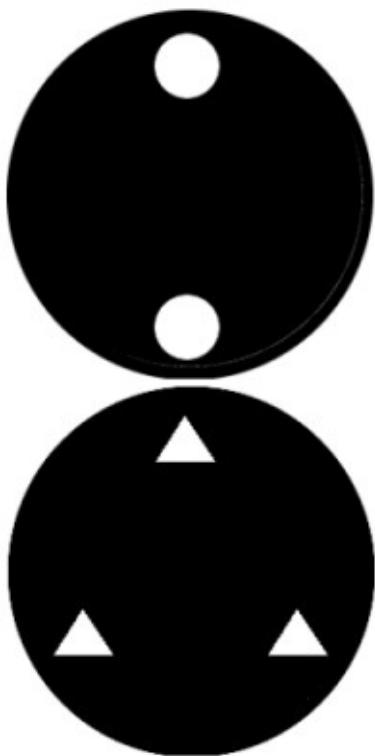


Fig. 55

Adjusting the focus will cause the images to either converge or diverge. When they converge to a single image then the optical system is in focus as seen in Figure 56. When the focus is long or short (top and bottom graphics) two star images are seen. When in focus these merge into the single star shown in the centre graphic.

The drawback with a Hartmann mask is that there is no inherent way of knowing whether one is inside or outside of focus, and therefore no indication which way the focuser has to be racked to get the images to converge. This may not sound like a great drawback, but some folks, especially those operating their telescopes remotely feel that having that indication is a good idea.

There is a Hartmann mask template generator on-line at

<http://www.billyard-ink.com/Hartmann.shtml>

Focusing masks are opaque sheets that are placed over the front of a telescope to block most of the light from entering. The light that is allowed to enter does so only through strategically placed holes in the mask to either create multiple images or a diffraction pattern. These are used as focusing tools and are designed so that the pattern created at focus is different from that created out of focus.

The simplest focusing mask and possibly the oldest is the Hartmann mask. This may have two or several holes in it allowing light to enter. Technically a mask with two holes is a Scheiner disc but in common usage all of these are known as Hartmann masks. Some have round holes and others have triangular holes that add diffraction spikes to the images created but they all work the same way. Shown in Figure 55 are the two types of masks.

The way that a Hartmann mask works is that the light impinging on the optics will, if out of focus, create as many images as there are holes in the mask. With the mask above left two images will be created whether the optics are inside focus or outside focus. The mask below left will create three images along with six diffraction spikes.

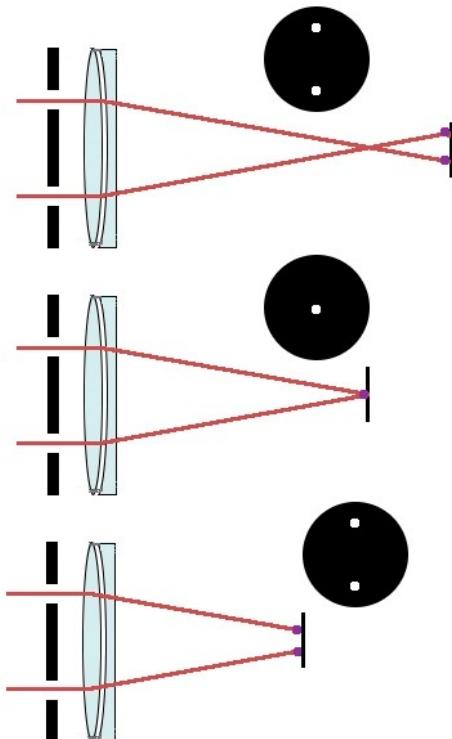
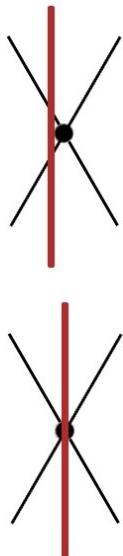


Fig. 56

Another focusing mask that is a bit more complicated than a Hartmann mask is the Bahtinov mask. This was designed by a Russian amateur astronomer named Pavel Bahtinov. It consists of three grids of straight lines in the mask; two angled outward and one below those that bisect them.

A Bahtinov mask is placed over the front of a telescope that is pointed at a brightish star. The image of the star will be a diffraction pattern shaped like an X with a long spike running through the X.

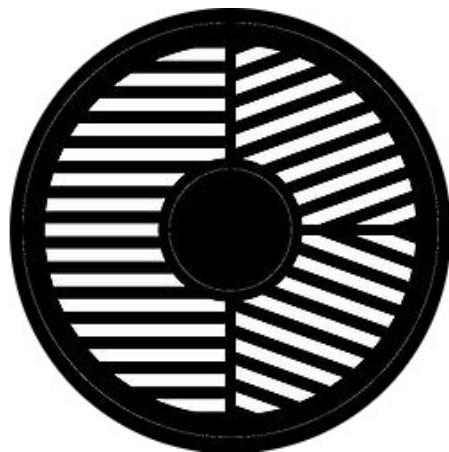


*Fig. 58*

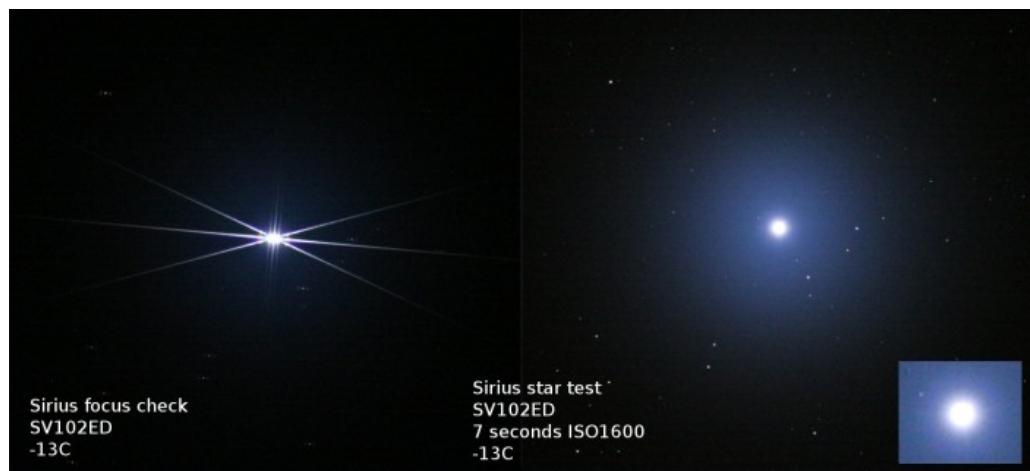
When in focus, the long spike perfectly bisects the X. At other positions the long spike will be on one side of the X or the other as shown in Figure 58.

Achieving critical focus is very simple if the image can be inspected at a high enough magnification. I have found that LiveView on my modified DSLR does magnify the image enough so that rough focus can be achieved but I have to take short exposures and inspect them changing focus between shots in order to get perfect focus.

When taking images with the Bahtinov mask in place it is very easy to see whether the optics are in focus or not. With a DSLR I can zoom in a lot farther on an image being displayed on the LCD after shooting than I can using the LiveView therefore making my judgement of focus much better. The image in Figure 59 of Sirius through a Bahtinov mask and then with the mask removed shows the diffraction pattern..



*Fig. 57*



*Fig. 59*

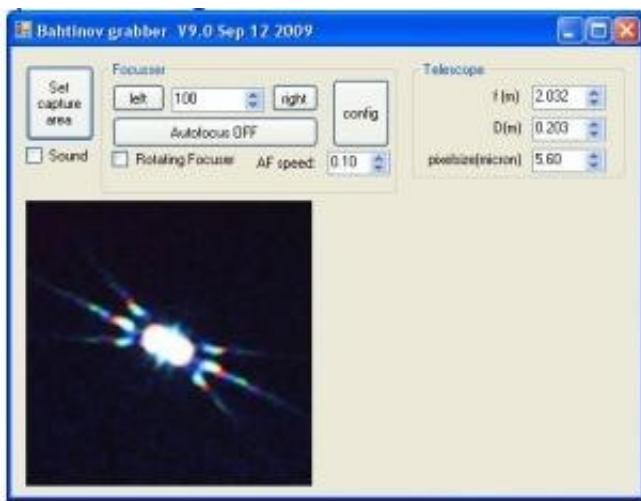


Fig. 60

The auto-focus routines are in alpha as of this writing but with ASCOM providing the interface it shouldn't be too long before accurate and inexpensive auto-focus is available to all.

Figure 61 shows a Windows frame-grabber displaying the Bahtinov diffraction pattern with the Bahtinov Grabber capture window showing its 'in focus' display.



Fig. 61

The last focusing mask that I will discuss is a newer mask than the Bahtinov that works along the same lines in that the diffraction pattern is analyzed to test focus. This is the Carey mask and was invented by a British amateur.

This mask was invented to make *exact* determination of focus easier and yet still provide an indication of which way to move the focuser in order to achieve focus. To do this the mask must be placed on the telescope in the same orientation each time it is used.

The Carey mask has two sets of slots cut in with one set at 12 degrees and the other at 10 degrees. They create an X-shaped diffraction pattern with two X's overlaying each other. When inside of focus one side of the X will be splayed apart and when outside of focus the other side will be. When the two are evenly overlapped then the optical system is in focus as can be seen in Figure 63 where the right hand panel is in focus and the other two are approaching.

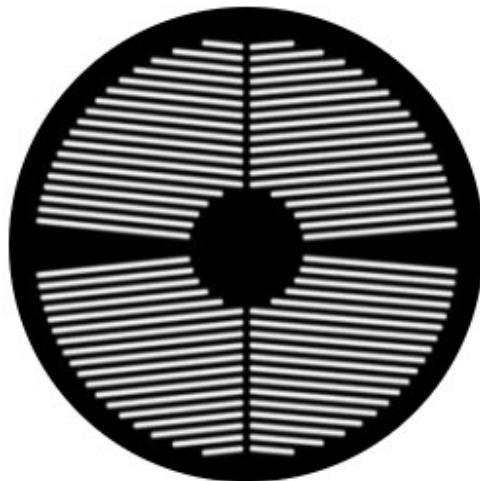


Fig. 62

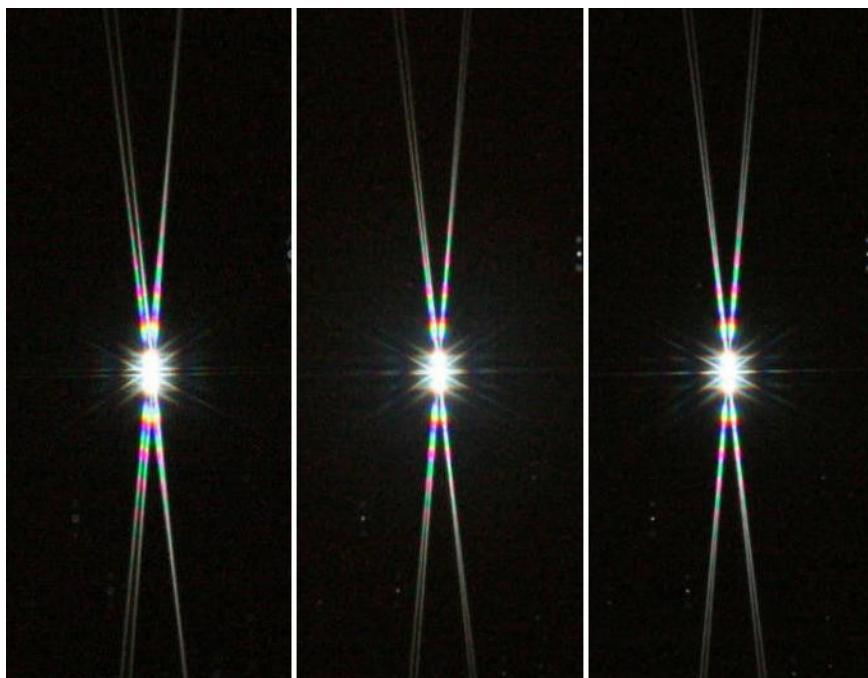


Fig. 63



Fig. 64

When in perfect focus the two X's can be seen to be evenly splayed as Figure 64 shows.

## Automatic and Remote Focusing

### Automatic Focusing

There are software/hardware systems that can automatically focus an image under computer control. These work by taking an image, or looking at a video stream, and measuring the full-width-at-half-maximum (FWHM) size of a star image (Figure 65).

These systems are not expensive and comprise of a highly controllable motor, usually a stepper motor, along with control and communications circuitry. They generally talk to a computer through an RS-232 connection.

In order to focus automatically, the software needs to have control of the imaging camera. It will then take short images and analyze a star. Short images work best as the star image selected should not be saturated. The software can then generate a brightness curve such as the one shown above and measure the diameter of the star at  $\frac{1}{2}$  of the maximum value. The optical system is then refocused if needed and further images taken until the FWHM reaches the smallest value; at which point the image is in focus.



Fig. 66

different focusers and Technical Innovations also provides software to drive the system. ASCOM drivers (a client/server architecture for running astronomical gear) are available so that other vendor's software should be able to access the hardware.

A new offering on the market is the Armadillo from Lunático Astronomía in Spain. It connects to a computer and can control two stepper motors at once. It is compatible with the

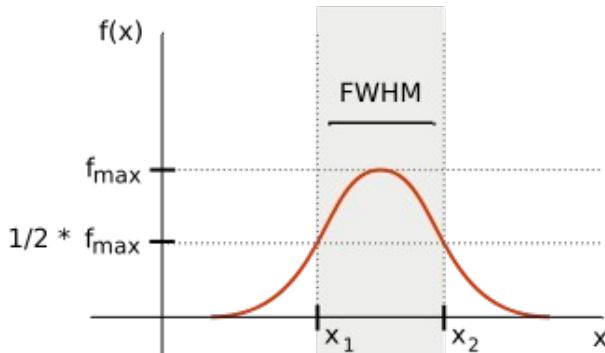


Fig. 65



Fig. 67

Robo-Focus mentioned above and the stepper-powered focusers from Starlight Instruments or Moonlight Telescope Accessories. It too is ASCOM compliant.

### Remote Focusing

Focusing a telescope remotely is something that is of great advantage whether it is done automatically or manually at the keyboard. Several companies offer computer controlled focusers or hardware to mate to powered focusers.

From Jim's Mobile is the JMI PC Focus Control that plugs into a USB port and allows control of a DC motor powered focuser such as the MOTOFocus, also from JMI.

The PC Focus Control comes with software to run the unit and needs no special drivers. It takes all of its power, including that for the motor, from the USB connection and therefore is limited in the size of motor that it can power.

Another offering that allows remote focusing is the TOGA LX Guider/Focuser from Two Old Guys Astrogear. This unit connects to a PC using a USB cable and will drive two DC motors of any type from the software provided. Drivers for the USB connection are provided and the unit is ASCOM compatible to a degree. The standard LX200 ASCOM driver will allow use of one motor.

The TOGA unit also has an ST-4 compatible auto-guider port, DSLR shutter control and adjustable fan power. With its proprietary software two focus motors may be powered and controlled with adjustable speed or 'pulse focus' for fine control.

For information on a DIY implementation of a powered focuser see the DIY section.



Fig. 69

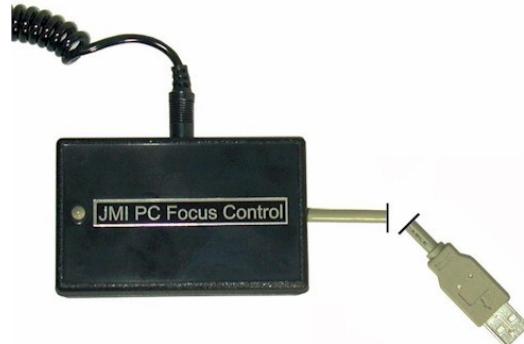


Fig. 68

## Field Flatteners, Focal Reducers and Coma Correctors

One accessory that has become almost de rigueur in imaging these days is the field flattener. Almost all telescope designs have some curvature of field which means that the focal plane is not a flat surface but is a section of a curve. Some types show more curvature than others but very few designs are truly flat without a bit of help. The ones that are touted to be flat still aren't flat, but are flat enough over the field they will be working at.

Curvature of field manifests itself in stretched stars in images. The stretching effect starts immediately on departing the optical axis towards the edge and is most profound in the furthest corners of an image. The stretch is radial so the stars look like ovals pointed towards the centre of the image. Figure 70 shows the effect of curvature.

In the graphic below the left image is a refractor objective with three sets of rays coming to focus to show the curvature of field. This is both highly stylized and grossly exaggerated; so if you're a budding optician ignore the drawing and concentrate on the theory. In the right graphic a two-element field flattener has been added.



Fig. 70

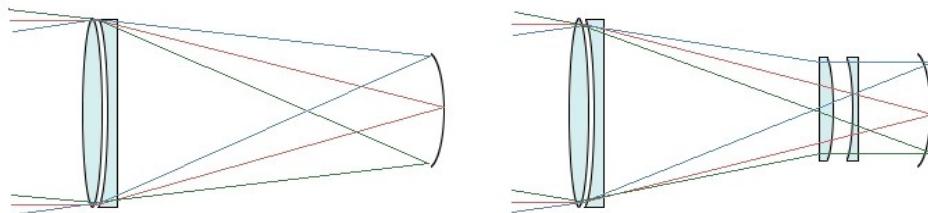
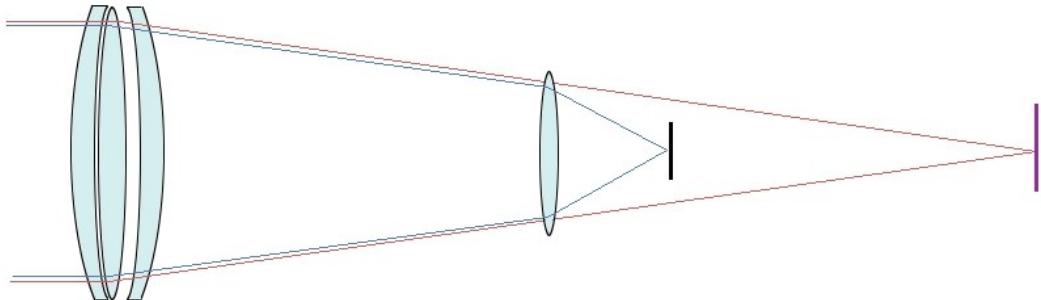


Fig. 71

Focal reducers are lenses that are placed in the light path to shorten the focal length and thereby increase the field of view. This is shown in Figure 72 with the normal focal plane shown in mauve and the new focal plane in black.



*Fig. 72*

Focal reducers and field flatteners can be purchased separately but often they are bundled into one unit as shortening the focal length tends to increase the effect of curvature.



*Fig. 73*

Figure 73 shows the Williams Optic Flattener III reducer flattener. This unit has a camera's T adaptor incorporated into it and reduces the focal length to 80% of original; so an f/6 refractor would become an f/4.8 refractor with the field flattened. It will work for many telescopes.

In Figure 74 is a field flattener/focal reducer of a design offered by several manufacturers. This one is a Meade f/6.3 reducer that is designed to flatten the field of their non-ACF Schmidt-Cassegrains and change the focal ratio from f/10 to f/6.3. These are usable either visually or photographically.



*Fig. 74*

Some forms of reflecting telescope, notably those of Newtonian design, display a form of off-axis aberration known as coma. This makes stars turn from points of light into little 'seagulls' or wedges. The farther a star is from the optical axis the greater this effect. Faster optical systems display greater amounts of coma than slower ones (f/5 vs f/8 for example).

To correct for coma makers of Newtonian astrographs generally build in a set of lenses to both return the stars to pin-points and also flatten any curvature-of-field. For telescopes that don't have coma correction built-in Baader Planetarium offers the MPCC (Figure 75) and TeleVue has the Universal ParaCorr (Figure 76). Both of these drop into a 2" focuser and work with telescopes within a fixed range of focal ratios. In the case of the MPCC the range is from f/4 to f/6 and for the ParaCorr f/3.5 to f/8.

The MPCC doesn't change a telescope's focal length while the ParaCorr does show a small magnification effect so if focal length and field of view are of prime importance this should be taken into consideration.



Fig. 75



Fig. 76

Proper collimation of a telescope equipped with a coma corrector is extremely critical and should therefore be checked and adjusted if needed before every imaging session.

The TeleVue offering accepts all of that company's 2.4" imaging system accessories while the MPCC is threaded for any standard photographic T-ring. Proper flange-to-sensor spacing is maintained by both.

## Dew Control

Any telescope in a humid climate that has an objective lens or a corrector plate at the front of the tube will eventually need some active method of fighting dew. Optics cool rapidly at night and eventually they will drop below the ambient temperature to a point where any moisture in the air condenses out onto the lens (dew point). Once your optics dew over your imaging session is finished.

The dew-free time that is spent in the field can be lengthened by placing a simple dew shield over the front of the telescope. This passive device limits the amount of sky open to the lens and therefore slows the cooling of the lens enough to keep things going for a while longer, but not indefinitely. Eventually though some active method of fighting off the dew must be considered.

There are many anti-dew systems on the market these days which range from very simple units to very complex and expensive devices that can be remotely controlled. No matter the price or complexity they all work the same way, by providing just enough heat to keep the optics slightly above ambient temperature and thereby never letting the optics drop in temperature to the dew point.

When an electrical current is run through a resistive load that load will heat up. Connecting a resistor directly to 12 V would have the resistor becoming too hot so what all anti-dew systems do is to turn the current on and off rapidly varying how long the current is on against how long it is off. This is known as Pulse Width Modulation.

The two waveform graphics show how a heat strip is turned on either 30% or 70% of the time. The

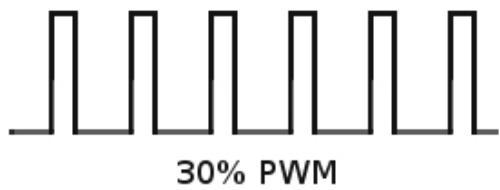


Fig. 78



Fig. 79

strip powered on 30% will radiate less heat into the optics.

Dew control has been Kendrick Astro Instruments' bread and butter for years and they offer many controllers, one of which is sure to meet your needs. Their Premier Controller is shown in Figure 77 as



Fig. 77

an example. They also offer resistive anti-dew strips which attach to the front of the telescope tube via Velcro and models that attach to just about anything else that needs heating.



Fig. 80

How much heat is needed is a question that is asked often and the answer is 'generally not a lot'. Most of the time I spend in the field my heat control is set to either 30% or 40% and is only turned higher on the rare occasions that I've missed the start of dew and need to clean a misty lens.

Thousand Oaks Optical makes a very inexpensive heater controller that has four separately settable channels (Figure 80). These are compact and effective.

When connecting any PWM heat controller to the power supply remember that the current being drawn doesn't change just because the loads are being turned on/off rapidly. If a heater load draws 3 amperes at full power it is still drawing 3 amperes for those times that it is turned *on* in the cycle. Select cabling and fuses accordingly.

Positioning a heat strip is a personal preference. On my refractors I position them just behind the objective cell on the main tube. Other people wrap them around the dew shield of the telescope. I don't think that either way is better than the other but putting them on the tube means I can buy a slightly less expensive strip.



Fig. 81

## USB Hubs

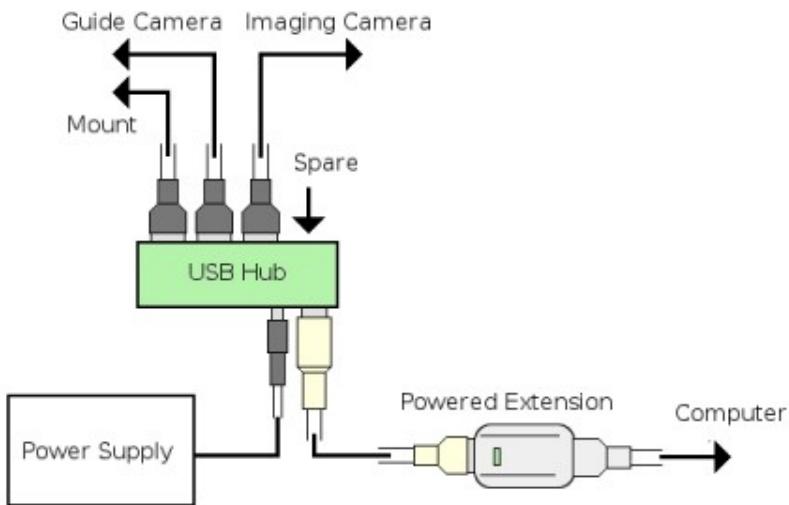


Fig. 82

fixed installations most hubs ship with an AC/DC adaptor (wall-wart). Either way, you get to go over the 500mA limit..

Another consideration is the cabling that will be needed to get from the computer to the hub. The USB 2 specification limits the cable length to 5m. Any longer run may degrade the speed and/or stability of the connection. To get around this limitation use a powered extension cable. These are available from many sources on-line for about \$30 and allow a second 5m cable to be used to increase the run to a total of 10m from the computer to the hub. With some it is possible to span even further by adding more powered extensions, but for long runs perhaps a USB/Ethernet hub would be preferable as long as full USB2 speed isn't required.

How many USB ports are needed is a function of how many things you want your computer to 'talk' to. Normally a three-port hub would be fine, but if something like the TOGA LX Guider/Focuser or GPUSB from Shoestring Astronomy will be in use to control things, four or more might be needed. These will be for:

- ◆ Computer control through a planetarium program
- ◆ Image download from and control of a DSLR
- ◆ TOGA LX Guider/Focuser
- ◆ Guide camera

If a computer is to be used to talk to all the many bits and pieces a USB hub near the mount somewhere will be a necessity. Most guide cameras, focusers and other gear have USB connections but if they don't converters are available. Using USB means that only a single line to the computer can be operating many devices.

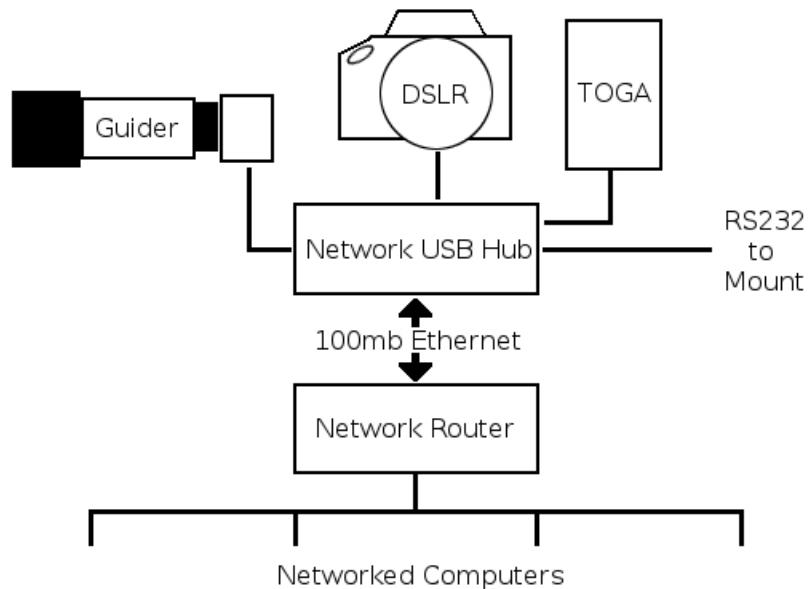
USB can only source 500mA of power per port on a computer and with all of the things plugged into a hub it is easy to go over that current level. In the field an adaptor to turn 12 V into whatever the hub uses will be needed. For



Fig. 83

To control a mount it will probably be necessary to purchase a USB to serial dongle as most mounts these days don't come with a USB connection. I have two of these of different makes, both of which work perfectly with my Celestron CGE and my HEQ5

For those situations where a longer run than 5 or 10m is involved Belkin makes an ethernet-to-USB four-port hub that seems fairly nice and allows access to many USB devices from any computer on a network; really a good idea. Ethernet allows a 100m run of cable which can put a telescope a long way from a warm-room and still be controlled almost completely if a multi-function device such as the TOGA LX Guider/Focuser or other unit is being used. There are some limitations as to which devices the hub can control but it runs from 12 V DC so powering the hub should be easy.



*Fig. 84*

Building a DC power supply to run a unit like this is quite simple which will mitigate most over-current issues while running cameras etc. For more information see Appendix IV.



*Jon Gunning shot this image of Omega Centauri at the Texas Star Party. The telescope was an Astro-Physics 130 mm refractor on an A-P 1200GTO mount. Camera was a Canon 20Da. Twelve 5-minute subs were shot at ISO800.*

## Filters

Filters are one of the most useful accessories that an imager can add to their kit list and in some cases they are required. As mentioned earlier in this document for CCD colour imaging red, blue and green filters will be required to do any colour imaging. Other filters either filter out certain wavelengths of light (broadband) or pass only certain wavelengths of light (narrowband).

Filters come in many formats depending upon their intended use. The most common in the astronomical world are the 1.25" and 2" formats with the former almost always limited to visual observing. These screw into the bottom of eyepieces, diagonals etc. but are also used in filter wheels or prime-focus adaptors.

A recent addition to the filter maker is the 'EOS Clip' from Astronomik (Figure 86) which fits into the front of a Canon DSLR camera ahead of the mirror. This means that an astronomical filter can also be used for special effects in terrestrial shooting and also that the same filter can be used for imaging with both a telescope or a camera lens; truly versatile. It didn't take long for other manufacturer's to get into the act with their own versions. The most interesting of these is from Hutech which has an adaptor that clips into the camera body and uses low-profile 37 mm filters.

For those imaging with Schmidt-Cassegrain telescopes, or any other telescope with an SCT thread attachment most filters are available in a screw-on cell that will mate with the thread.

Filters should be made from proper optical glass, with sides polished plane and parallel then coated properly for their purpose. A set of filters used for LRGB imaging should be par-focal (exhibiting no change in focal point when changing filters).

For ease of use and for allowing remote operation, CCD imagers that shoot in colour using filters will use some form of filter wheel such as the one from Apogee (Figure 87) which mounts ahead of the camera. These usually holds 4 or 5 filters which can quickly be moved into place as needed. .



Fig. 85



Fig. 86

Other than the red, green and blue filters are those known as narrowband filters. These filters block everything but a specific wavelength such as hydrogen-alpha (Ha), doubly ionized oxygen (OIII) etc and are used by CCD photographers who wish to take specialty images. Some will, instead of taking a 'luminance' image with their CCD will substitute an Ha image for a different effect... or switch other filtered images for red, green and blue to try to build a more pleasing 'palette' of colour.

One of the favourite colour sets or 'palettes' as they're known is the Hubble Palette. This swaps the light of ionized sulphur (SII) for red, hydrogen alpha for green and doubly-ionized oxygen (OIII) for blue. This gives a completely different twist on deep sky objects.

### **Light pollution or High Contrast filters**

These filters, also known as broadband filters, are offered by several makers and are all designed to block the wavelengths of light pollution and possibly enhance the wavelengths of nebulae. Among the favourites are the Lumicon UHC, Orion SkyGlow and Hutech IDAS Light Pollution Suppression filter. These are all offered in 1.25 inch, 2 inch, SCT and other formats. Following is a snippet of description from each vendor's website.

#### **Lumicon Ultra High Contrast filter**

...unbeatable for revealing nebulosity. This is achieved by passing three nebula emission lines-the two doubly ionized oxygen lines (496 and 501nm) and the H-beta line (486nm)-while blocking light-pollution and Sky Glow.

#### **Orion SkyGlow Astrophotography filter**

...custom designed the filter to selectively block the specific wavelengths of light associated with urban sky glow, letting the light emitted from deep-sky objects shine through...

#### **Astronomik CLS filter**

...blocks the light of the spectral lines of mercury and sodium-vapour lamps and lets the largest part of the visible light and H-alpha emissions pass.



*Fig. 87*

## Hutech Light Pollution Suppression filter

...designed to suppress the common emission lines generated by artificial lighting, yet allow the important nebula emission lines to pass, thus enhancing the contrast of astronomical objects...

Beyond creating a new colour palette narrowband filters can offer significant enhancements of many deep sky objects. Planetary and supernova remnants often are better imaged with an OIII filter while an SII filter can offer increased contrast in the deep red for supernova remnants from light polluted skies with, of course, cameras that are able to record this wavelength. A modified camera is not needed for OIII. Figure 88 shows an image of the Dumbbell Nebula taken by Robert J. Vanderbei with an OIII filter.



Fig. 88

One of the most popular filters with both CCD and now DSLR imagers is the Hydrogen alpha filter. This light which is at a wavelength of 656nm in the deep red. This light, which is the light emitted by the first transmission in the Balmer series of hydrogen spectral lines is emitted strongly in any areas where hydrogen is being ionized. There are many deep sky objects that contain a lot of hydrogen that don't radiate much in visual light but do emit strongly in Hydrogen-alpha (H $\alpha$ ).

Ha filters come in several forms, each with a different 'bandpass' specification. The least expensive will transmit a band in the vicinity of 12nm wide while 'tighter' filters can go down to 4 or 6nm. Figure 89 is a monochrome image of the Veil complex in Cygnus I shot with a 12nm EOS Clip filter from Astronomik in a Hutech modified Canon 500D.

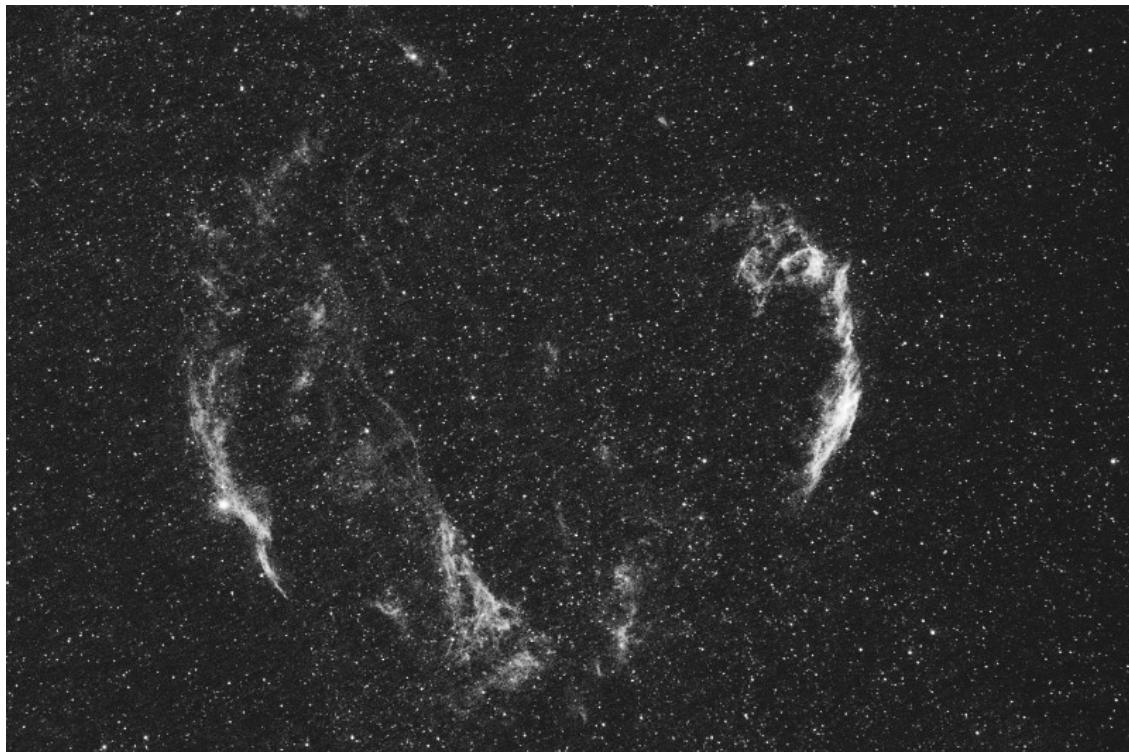
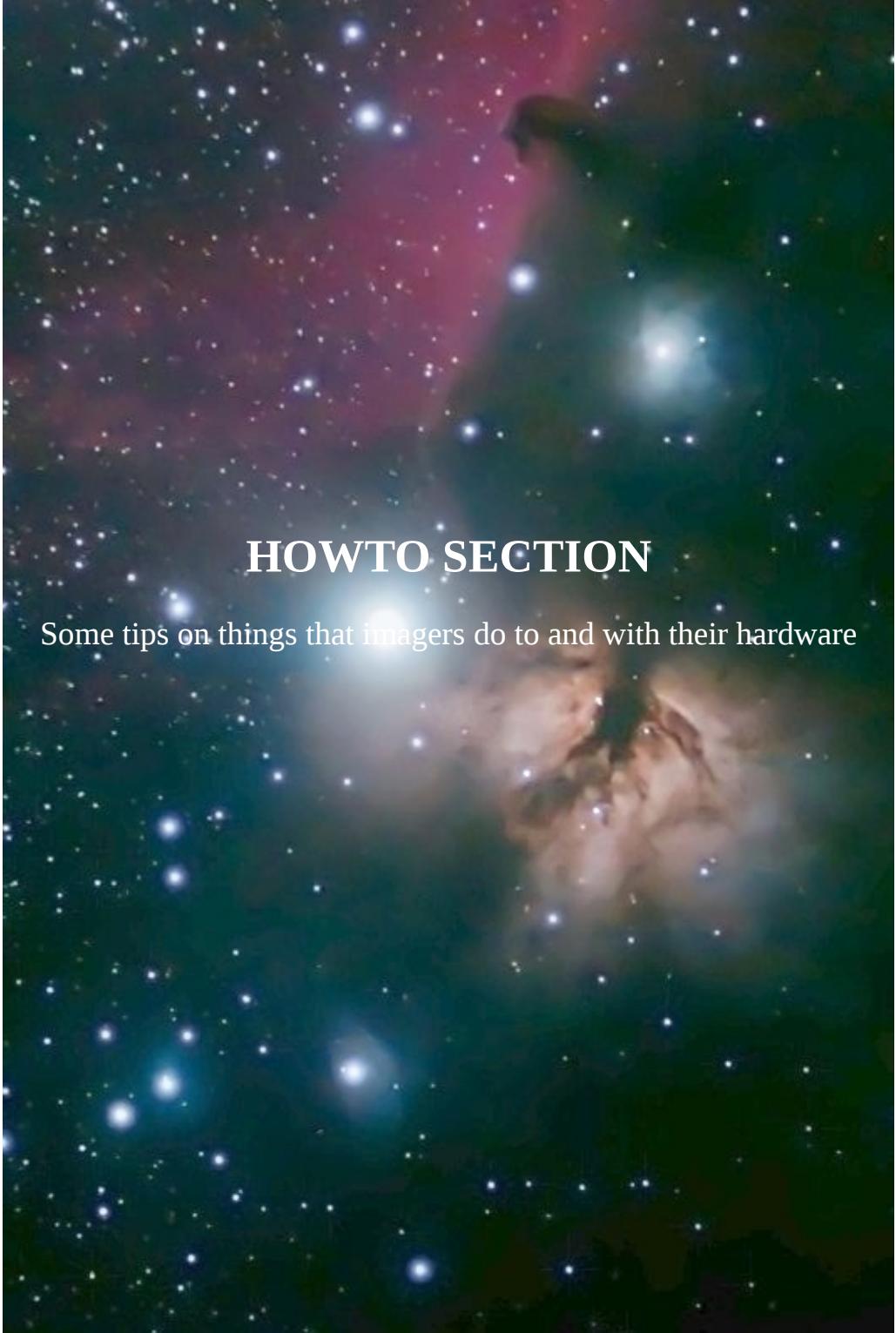


Fig. 89



## HOWTO SECTION

Some tips on things that imagers do to and with their hardware

*Alnitak Region by Rick Saunders*

## Differential Flexure

The goal of all astro-photographers is to have their target framed correctly, the exposures timed correctly and to have the stars in the field turn out round. Nice, round stars means that the guider was working and that there was no shift in the optical/camera system throughout the length of exposure chosen. Images with oval stars can be caused by several issues but the most common problem is 'differential flexure'.

An imaging system showing differential flexure (DF) has guiding optics and imaging optics that can move relative to each other. This means that even though the guider may have been locked solid on a guide star for the whole exposure sequence, the imaging system slowly (or worse, quickly) changed where it was pointing, causing stars (and everything else) in the image to smear. Differential flexure can be one of the most exasperating problems to track down but, if approached methodically, it can be eradicated.

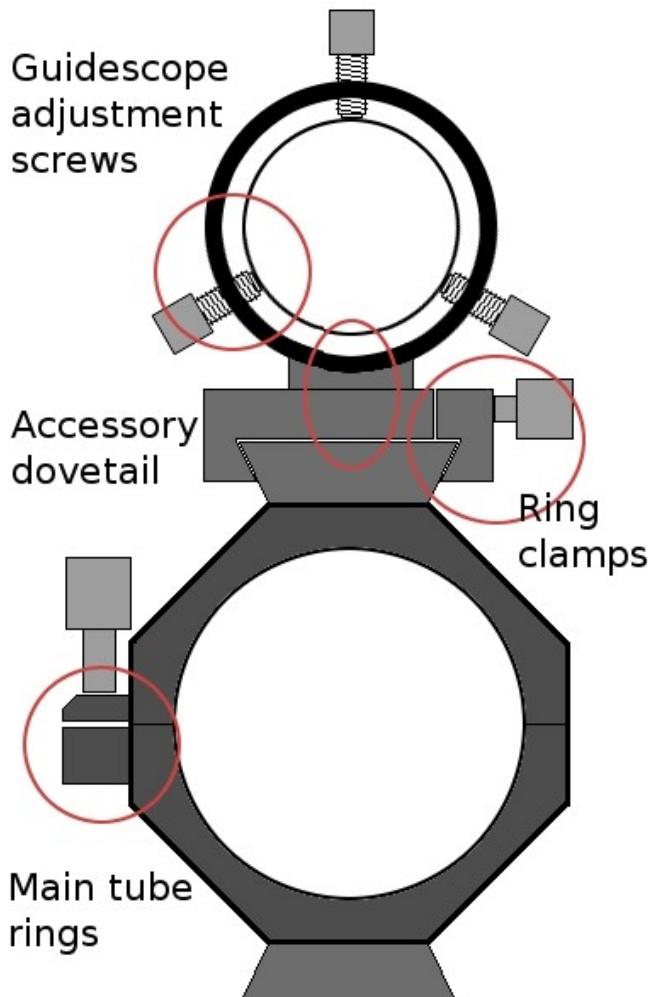


Fig. 90

The first place to look for DF is in the method or methods used to mount both the imaging and guiding optical tubes. Most have many different parts which may be from different sources. This offers much in the way of versatility but also provides a lot of places where flexure can creep in. These are:

1. The connection between the imaging scope's rings and the guide scope's rings. If a side-by-side setup is in use this still is pertinent, the scopes are just offset.
2. The accessory bar on the imaging scope. Check that it is properly and tightly connected.
3. The guide scope ring attachments to the accessory bar. If a dovetail system is used these should tighten well with left-over 'slack' when tight.
4. The hinge and locking mechanism for the imaging tube rings. Again, these should tighten with a little slack left over. If they come together completely without properly clamping on the

optical tube then the tube can move. If the rings are slightly too large for the optical tube then they should be replaced or some kind of shim material added so that they properly hold the tube.

- The guide-scope adjustment system. The old 'three thumbscrews at 120 degrees' method allows a lot of adjustment room for finding a guide-star but when set the adjustment screws should be tight enough to not allow the guide-scope to move at all.

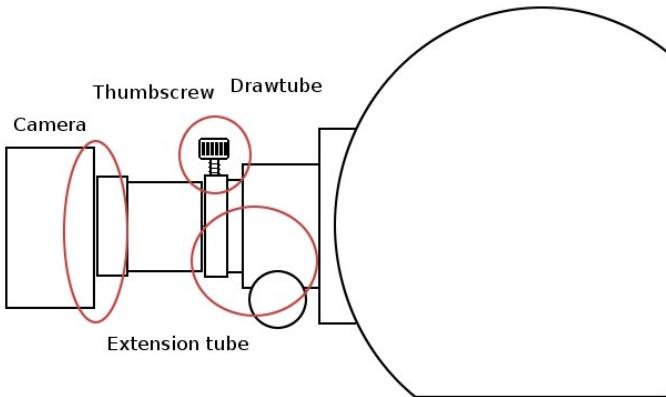


Fig. 91

When tightening split-rings never tighten them enough to compress the optical tube. While this may sound silly a lot of pressure can be exerted by a hand-screw.

Loose screws are easily remedied with a hex-key or screwdriver. If it is found that things loosen over time then the judicious use of Lock-Tite or a similar compound applied to the threads could keep them in order. Ask a professional about the use of Lock-Tite as it comes in various 'strengths'. If there is the possibility that some day the screw *has* to come out then use a type that allows this; some don't.

If tring mounting clamps don't perfectly tighten onto the accessory dovetail then it might be necessary to remove some material in the 'slack' that is taken up on tightening to allow the clamps to close farther. Alternately some shim material between the clamps and the accessory dovetail could be used to get things tight.

The next place to look is at how the camera is attached to the imaging tube. These days most astrographs come with some form of easily adjustable focuser. Whether this is a Crayford or a rack-and-pinion type there will be a draw tube that moves in and out of the focuser to allow the camera to come to the focal point. If there is any slop in the focuser the draw tube could sag over time as the orientation with reference to gravity changes. Anything such as an extension tube between the focuser and the camera has to be checked to make sure it can be tightened properly.

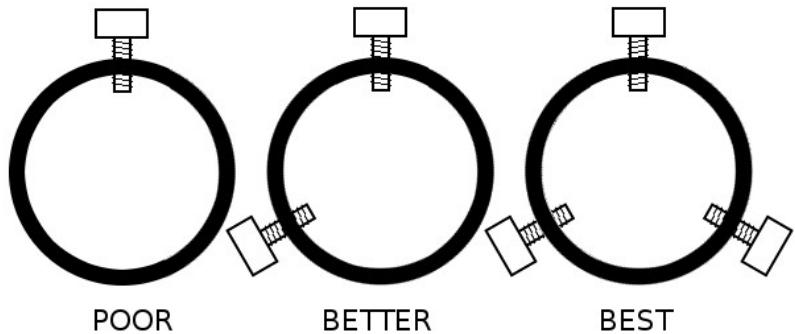


Fig. 92

The best way to have a focuser set up is to have the draw tube kept well inside the focuser body with the camera at focus. If the draw tube is mostly exposed then the weight of the camera can cause it to sag. The use of well-designed extension tubes can allow the focuser's draw tube to stay well supported inside the focuser. Make sure that the connections between the focuser and extensions are tight and square.

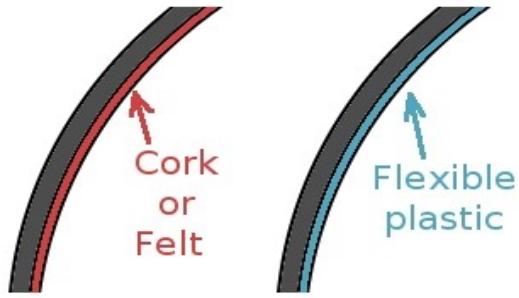


Fig. 93

that the thumbscrew doesn't mar the barrel of an eyepiece. A single thumbscrew is not optimal for imaging. Try it; place something in the focuser and tighten the thumbscrew. Try to move it. Many times it will rock back and forth as it is only contacting the inside of the focuser in two places 180 degrees apart. This allows motion perpendicular to the line of contact.

This problem can easily be remedied with a drill press and a tap and die set. A second, or better yet, two more thumbscrews can be added (Figure 92) to allow a proper 3-point contact between components. The advantage of having three screws is that they allow a tiny bit of adjustment in where an accessory's centre is located.

If everything isn't tight then adding some force to the end of things will cause flex. This could be a heavy cable such as those found on older serial or parallel cameras, or the captive cable on an ST-4 guide head. Heavy cables that hang not only put a force on the end of an optical train, but a force that could change direction as the telescope tracks. The easiest way to remedy this is to add some form of strain relief to the cable run. I use self-stick cable ties on my side-by-side plate to hold up the heavy ST-4 camera cable. The cable is stiff enough that in the few inches left 'hanging' it provides its own organic support. Velcro, cable ties, or duct tape... all are good sources of strain relief. Make use of them.

In most split-ring systems the rings have some form of backing which allows the telescope to be clamped in place tightly while not marring the tube's finish. Cork and felt are two common materials

Some telescopes have rotating focusers that use three setscrews acting on a dovetail to keep them in place. If these setscrews are loose enough for the focuser to rotate then they are loose enough for the focuser to sag slightly or otherwise move as the mount tracks. The best thing to do in this case is to lock the rotating element in place. If camera needs to be rotated to frame an image then rotate just the camera.

When anything is attached to a telescope there are usually some thumbscrews involved. Most focusers these days come with a single tightening thumbscrew and a brass compression ring. These rings are there so

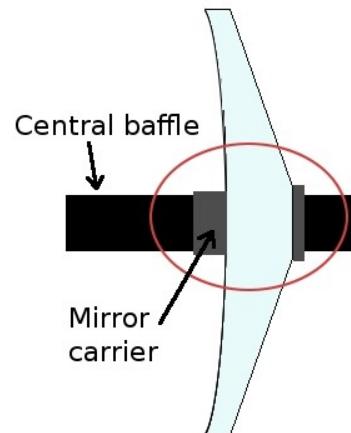


Fig. 94

used but both can display some small amount of give when a telescope tilts over. These materials can be removed and replaced with some .020 or .030 flexible plastic material from a hobby store. It only needs to be flexible enough to go around the curve of the rings. Hold the plastic in place with contact cement, this will not come apart and can take the changes in temperature that the system will be subjected to.

If an imaging tube is a Cassegrain type where the mirror moves on the central baffle (Figure 94) in order for the system to reach focus, a major source of flexure can be mirror-flop. On older SCT and MCT systems the mirror rode on a carrier that moved back and forth on the baffle with only a layer of lubricant to provide support. The few thousandths of an inch between the carrier and the baffle could cause an image to shift upward of 30 arcseconds.

New SCTs generally have pre-loaded ball-bearing carriers and may even have a mirror-lock to keep the mirror from tipping as the scope tracks. These can work very well but they then require an external 'zero image shift' focuser to add the needed adjustment. There are many of these on the market, any of which can add their own flexure issues.

In all instances when making parts eschew wood, soft plastics, rubber, etc. Make any parts out of aluminum or steel: something that won't compress, shift, shrink, grow or move.

As I mentioned at the top chasing down differential flexure can be a chore and very exasperating at times but the quality of images from a solid, non-flexing system is well worth the trouble. Just remember...if it is supposed to be tight, then tighten it.



*The East Veil shot by the author with a Canon/Hutech 500D and AstroTech 8" Imaging Newtonian on a Celestron CGE mount. Ten 7-minute exposures at ISO800.*

## Polar Scope Alignment

Every mount that has a polar-alignment scope should have some method of aligning it with the polar axis in order for it to be of use. Generally, this is not a difficult procedure and is most likely outlined in your mount's user manual but I'll run through it quickly.

Most of the polar scopes that I've seen use three setscrews spaced 120 degrees apart to set their reticule alignment. All had a cross-hair or an X the centre of the reticule that indicates the true celestial pole and which is to be used while aligning the scope.

Start by picking a distant target, something like the insulator on a power pole. Point the polar alignment scope at the target with the counterweight shaft horizontal. Adjust the mount's altitude and azimuth adjustments to place the cross-hairs on the target. Now, swing the counterweight shaft over to the other side of the mount.

The cross-hair will now be off target in some direction (unless the polar scope is already aligned) so use the reticule adjusting setscrews to move the cross-hair ONE HALF the distance back to the target. Then flip the counterweight shaft over to the other side and use the alt/az adjustment to put the cross-hairs back on the target. Repeat these steps until the cross-hairs stay on target while the counterweight shaft is flipped.

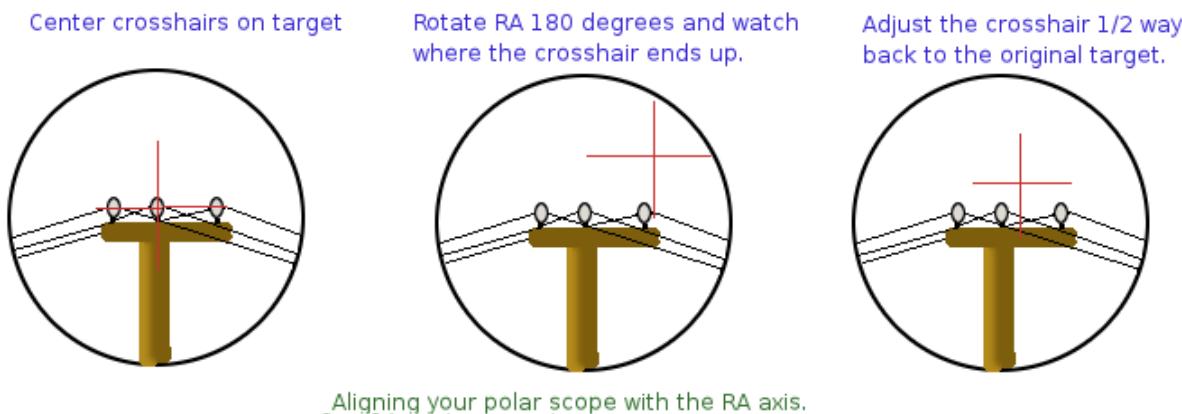


Fig. 95

Once the polar alignment scope is adjusted there may be date and time rings to adjust; these are outside the purview of this document as no two makes of scope will use the same method.

## Telescope Balance

Some people spend an inordinate amount of time balancing their telescope and all of the equipment that it carries. Normally, as a German equatorial mount should not be pushed much more than 50% of the rated capacity for imaging, there is actually some leeway with balance. And this is a good thing because perfect balance is not what should be the goal in many cases.

An equatorial mount runs at sidereal speed while tracking the sky. When a guider (either manual or computerized) makes corrections in right ascension it either speeds up the mount's tracking or slows it down. The direction that the mount is moving never actually reverses so there is no issue with backlash in right ascension. The goal to be achieved then is to have the worm and gear always engaged. The best way to do this is to have the mount balanced *east* heavy in right ascension. Figure 96 demonstrates this principle.

Looking SOUTH

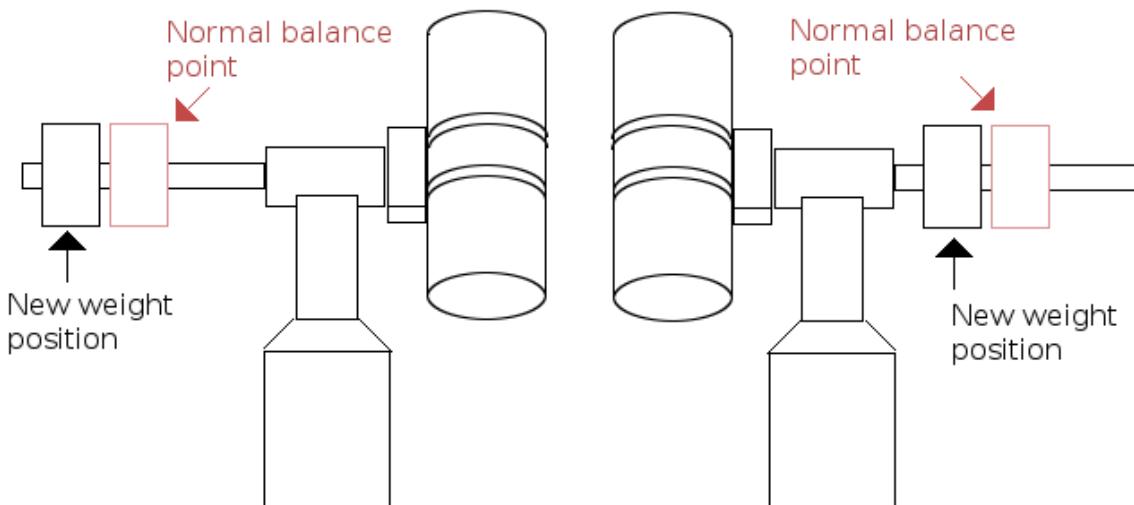


Fig. 96

The new weight positions shown will always have the telescope balance heavy east. Don't forget that after a meridian flip the counterweight will have to be repositioned.

Setting the optical tube nose heavy allows a worm-to-gear engagement in declination much like the east-heavy setup of the RA axis and is better than perfection in balance which may let the tube 'float' between the leading and trailing teeth of the worm gear. If needed a weight of about 2 kg could be

made that is adjustable on the optical tube allowing the balance to be heavy either way by moving the weight.

Along with a nose-heavy tube a mount can be slightly misaligned so that declination drift occurs in a north-only mode by setting the RA axis slightly west of north (looking north) and just past north (between the pole and the northern horizon). With this alignment the mount never reverses direction in declination removing declination backlash from the guiding process. Now, by 'slightly' I mean perhaps 10-15 arc minutes which is all that is needed.

I've found that my side-by-side unit does a very good job of providing a balance offset in declination for those times that the tube is pointed at or near the zenith. I just keep the SBS heavy on the guide-scope side and it keeps the declination gears engaged.

Fork-mounted telescopes generally don't come with any system for balance but there are several after-market setups that can be purchased, some of which are quite complex and allow '3D balancing'. Most are just a small dovetail or bar with a sliding weight such as the one from AstroEngineering in Figure 98. Adjustable weights are something that would be a good idea on any optical tube.

Be mindful that a mount has to be balanced with ALL of the gear that will be used in place. Don't balance before adding a camera, guide-camera, cabling etc. Also be cognisant of any changes in balance while slewing and tracking especially if there are off-centre loads such as when using a side-by-side setup.



Fig. 98

Looking WEST

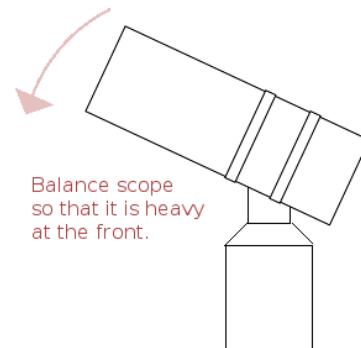


Fig. 97

## Drift Alignment

Having a good polar alignment is necessary for astro-photography and there are several methods of achieving this. Polar alignment scopes and software routines make it simple to achieve anywhere from reasonably close to almost dead on in polar alignment but not everyone has access to these. In this case the method to use is called 'drift' alignment; so called because it uses how a star drifts in a reticule eyepiece to adjust the polar axis precisely.

A good starting point is very helpful so start with a compass (properly set for magnetic deviation) and a level to get the mount close to being aligned.

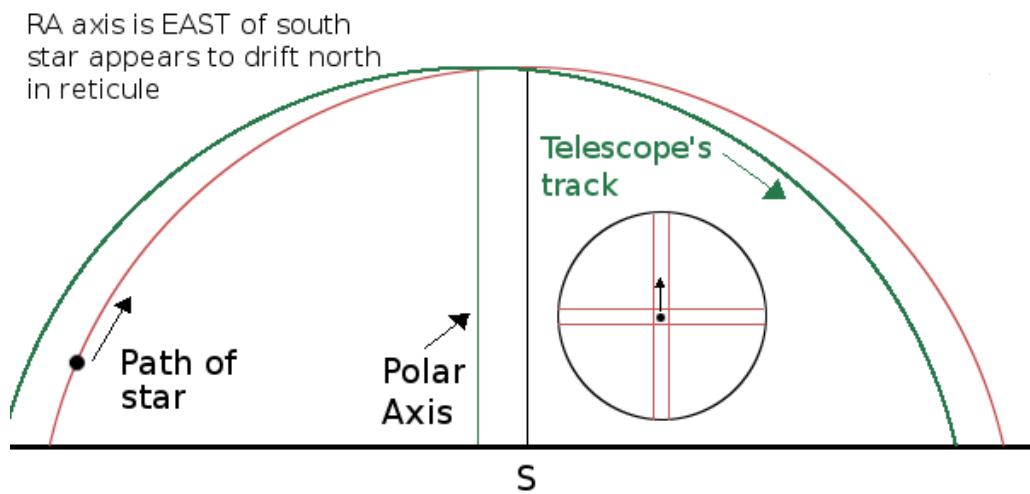


Fig. 99

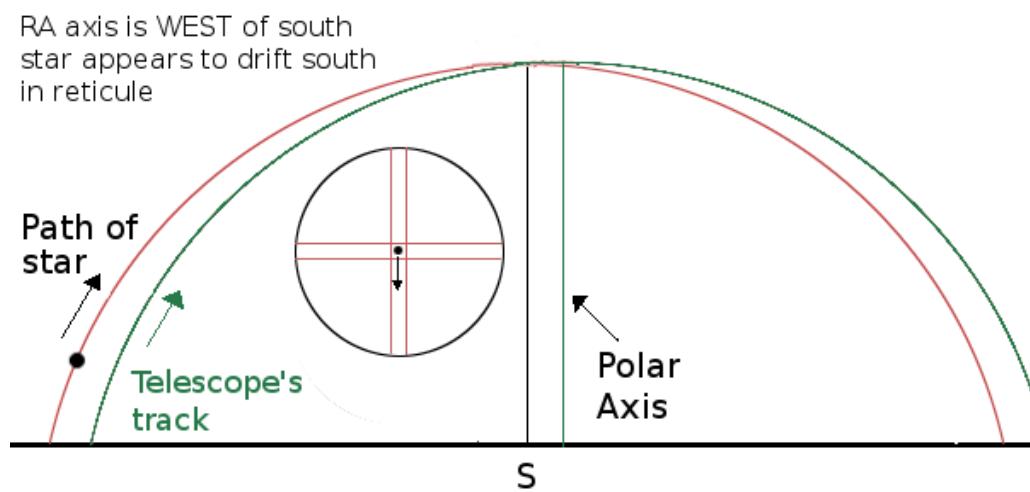


Fig. 100

Now select a star near the meridian close to the celestial equator and put the star in the reticule eyepiece and watch it for several minutes to watch for any drift. If it drifts north then the polar axis is pointing too far east if looking south. If the star drifts south then the axis is pointing too far west if looking south. Adjust the axis and re-centre the star. Continue until the star 'rides' a cross hair for 15 minutes.

Now select a star in the east near the horizon and around the celestial equator. Put the cross hair on it and again watch it for drift. If it drifts north then the RA axis is above the pole (between the pole and the zenith). If it drifts south then the axis is below the pole (between the pole and the north horizon). Adjust until the star again rides the cross hair for 15 minutes. Then go back to the meridian because things there will have gotten out of kilter.

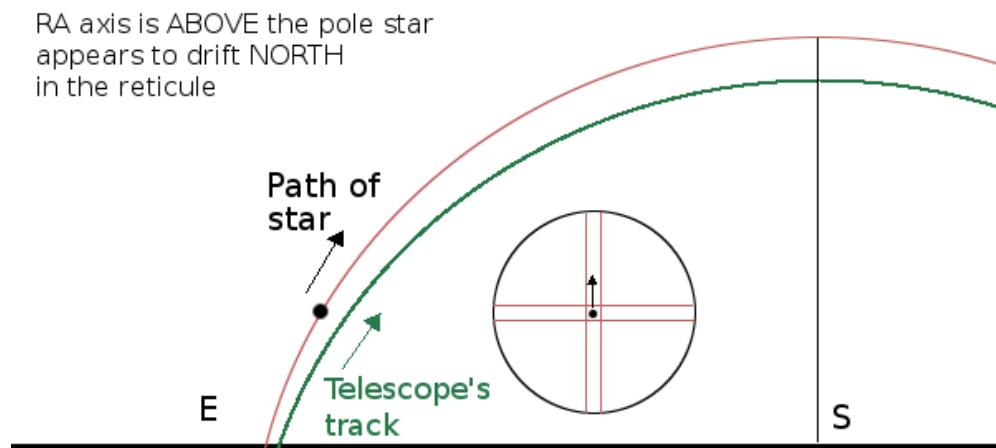


Fig. 101

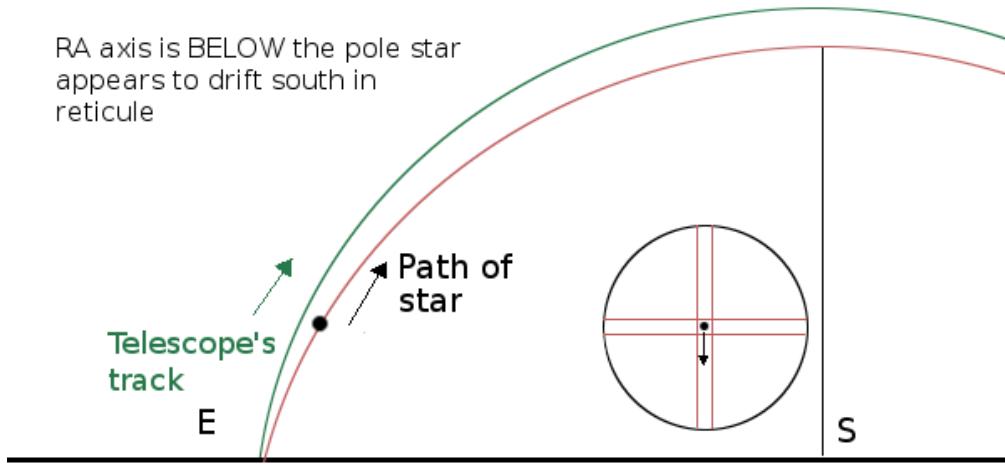


Fig. 102

The drift alignment method has the ability to put a mount dead-on the celestial pole. It is more useful for permanently mounted telescopes but I've done it for scopes that won't move for a few days. Other than that I've found that the alignment routine in my CGE's firmware can get me very close in a short time.

Notice that I said in the beginning that a 'good' polar alignment is necessary not a 'perfect' polar alignment is necessary. For the short subs that many people take good is fine as there won't be any noticeable field rotation in that short time. Also, remembering the mis-alignment mentioned in the previous section to allow easier guiding one may not want a perfect alignment.



*Image by the author of M27 taken with an unmodified Canon Rebel XT mounted on a Celestron C8 at f/6.3. Ten 5-minute images at IS800.*

## Exposure Control



Fig. 103

Once everything is setup, aligned and it's dark out it's time to start taking images. This means that some method of exposure control has to be in place. Whether this is simply a manual remote and a wrist-watch (not too accurate) or something a bit more complex the shutter has to open and close when needed. Those using CCD cameras will have the camera control software running on a computer so I won't dwell on these and move on to DSLRs.

DSLR cameras generally have some method of triggering the shutter remotely. This can either be via infra-red remote, stand-alone cable release or via a USB connection. I'll spend a few lines discussing the first and last of these and most of the time on the cable release.

Infra-red remotes allow operation of the shutter of some DSLRs using the IR port on the front of the camera. These can be expensive but a universal TV remote can be programmed to do the job (really...I'm not making this up). There are sites on the WWW that will explain the process for any specific camera.

Controlling the camera via a USB connection using something like Canon's EOS Utilities turns a computer into an intervalometer. If there is a computer at the telescope anyway there's not really much reason not to use the software that is provided.

If no computer is available a manual cable release can be used if is supported by the camera or an electronic intervalometer such as the Canon TC-80 (Figure 103), Nikon MC-36 or the camera-neutral TOGA Intervalometer (Figure 104) can be used. Each of these will allow a series of exposures to be programmed in for an automatic sequence.

Canon's TC-80 won't work with the Rebel series without modification and the Nikon unit is only for *some* of their cameras though they might offer other models of intervalometer that function with other models.. The TOGA device will work with any of them.

Nice things to look for in an intervalometer are the ability to do mirror lock up, programmable prefocus time and sufficient battery life to run a long imaging session.



Fig. 104

## Collimation

Any telescope system needs to be in collimation. This means that all of the optical components and their mechanical adjuncts are all properly aligned. Refractors generally don't need adjustment and with many it isn't possible. Any reflector will have the ability to be properly collimated.

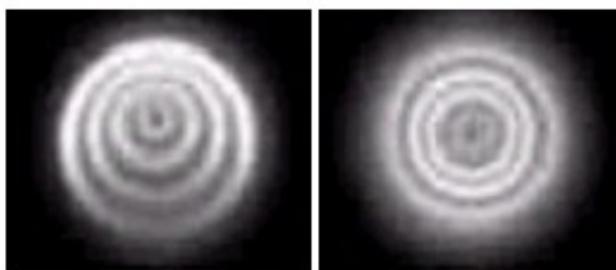


Fig. 105

A well collimated telescope will display sharper, more contrasty images and will allow dimmer stars or objects to be photographed. An example of an out-of-focus star image both out of collimation and in collimation is shown in Figure 105.

There are many different tools that are on the market to help properly collimate a telescope. These can be simple or quite complex. A précis of a few of them follow:

### A collimating cap

This cap can be as simple as a 35 mm film can with a small hole drilled in the centre of one end that is put in the focuser and looked through. Better is a 1.25" cap with a hole in it put onto a 1.25" eyepiece barrel such as in Figure 106. These are mostly used to properly orient the secondary mirror of a Newtonian reflector.

### A sight tube with cross-hairs (Cheshire or not)

These are very versatile tools but shy away from the cheap, plastic ones. If the sight tube is short enough this can double as the above-mentioned collimating cap. A Cheshire tube can, on its own, collimate a Newtonian reflector to a very high degree of accuracy if one's eyes can accommodate focusing very near and middling far. A Cheshire sight tube is shown in Figure 107.

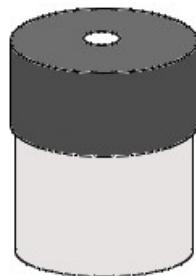


Fig. 106



Fig. 107

## A barlow lens

Any old barlow will do: single-element, achromatic or multi-element. Stick with an actual barlow though, as I don't know how this procedure will work with a TeleVue PowerMate unit. They're technically not barlows.

## A laser collimator

A good one. I've gone through two inexpensive lasers that weren't themselves collimated and therefore, other than for use with a barlow (explained later) pretty much useless. The Hotech self-centring laser (Figure 108) is very nice as are any of the units from Howie Glatter.



Fig. 108

## Auto-collimator

This is a small plug that fits in the focuser with a centre hole. Inside is a plane, polished reflector. It all works like those mirrors in old barber shops where you see multiple reflections stretching into the distance. Between the collimator and the primary mirror you get multiple reflections and if there is any mis-alignment this can be corrected by adjusting the primary mirror until all the reflections coincide.

The least expensive, yet very accurate Cat's Eye passive auto-collimator system has gotten rave reviews in Cloudy Nights and other venues.

## Newtonian Reflector

There are several parts to the basic Newtonian that all have to be aligned both mechanically and optically in order for the telescope to deliver the best image. Collimation starts from the eyepiece and works its way out so the first thing that must be looked at is the placement of the focuser and the secondary spider. These are both beyond the scope of this document as we'll assume that the focuser and secondary spiders have been properly installed.

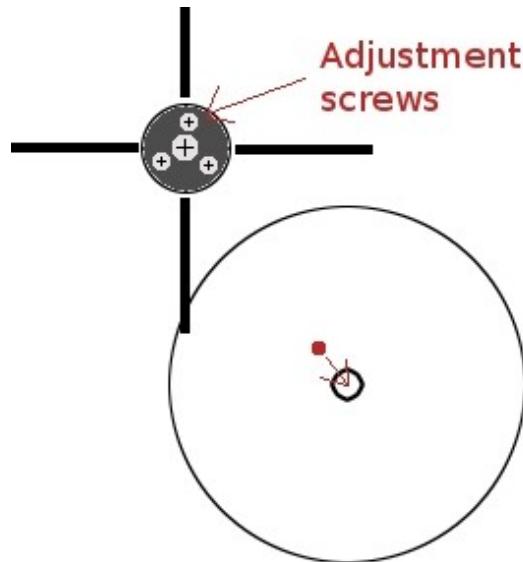
First in the sequence of collimation is the aligning of the secondary mirror. This has to be properly positioned in the optical tube to be able to pass the maximum amount of light from the primary mirror up the focuser.

To check on the positioning of the secondary mirror use a collimation cap as shown in Figure 106 (or a Cheshire sight tube). Looking into the telescope with the cap in place the secondary mirror should appear round and perfectly centred in the focuser. Most secondary mirrors can be adjusted along the optical path to centre by loosening a large central screw in the secondary holder. Once it is centred then the collimation cap is swapped for either a Cheshire tube or laser. I'll discuss the laser first.

Place the laser in the focuser and turn it on and look down the telescope towards the primary mirror. A laser dot should appear on the mirror. Adjust the three collimating screws in the secondary holder (don't touch the large central screw) to move the laser dot into the 'doughnut' on the primary mirror (Figure 109).

All Newtonians these days have central spotted mirrors but if yours doesn't you'll need to put one on by removing the main mirror, finding the centre and sticking on one of those paper reinforcements from a stationery store.

Once the secondary mirror has been aligned then it is time to move to the primary mirror. The mirror cells of all Newtonians should have 'push/pull' screws to properly orient the mirror. If the telescope has a truss tube then a short collimator such as those from Howie Glatter that protrudes from the focuser inside the telescope and is visible from the rear can be used.



*Fig. 109*



*Fig. 110*

If the telescope is a solid-tube type then a laser unit as shown with a cutout that can be seen from the rear can be used. Either way the idea is to adjust the primary to get the laser reflected back directly into the hole that it came out of (Figure 110 left).

The 'barlowed laser' method is also very effective. This method not only removes from the equation any mis-collimation of the laser device but also any 'slop' in the focuser. To do this, once you have aligned the secondary mirror take the laser out, insert it into a barlow lens then replace it in the focuser. Now the laser will illuminate the area around the central doughnut on the main mirror and reflect back the shadow of the doughnut as shown in Figure 110 (right). Adjust the push/pull screws to centre the doughnut's shadow.

Using a Cheshire sight tube such as the one shown in Figure 107 allows for a very accurate alignment of a Newtonian's optical path. The device is placed into the focuser and the alignment is checked by looking at the image seen of the various optical components.

To start with nothing is aligned (Figure 111 top). Place the Cheshire tube in the focuser and look in through the peep hole. The secondary (lilac) is not properly positioned so loosen the large central screw on the secondary holder (check the telescope's documentation) and move the secondary so that it is perfectly centred in the Cheshire (Figure 111 second graphic).

Now adjust the collimating screws on the secondary so as to put the cross-hairs on the primary mirror's (red) centre spot (Figure 111 third graphic). The green circles are the shadow of the secondary and Cheshire. The grey circle is the primary mirror with its hold-down clips.

Now adjust the primary mirror's adjustment screws or knobs until the shadow of the secondary and Cheshire are under the cross-hair (bottom graphic). Don't worry if the shadow of the secondary appears off centre. It is supposed to be.

With the view through the Cheshire as in the bottom picture at the right a Newtonian telescope will be in very accurate alignment.

Today's fast Newtonians being used with coma correctors require a high degree of collimation accuracy. Either a laser or Cheshire will allow this level of accuracy to be achieved.

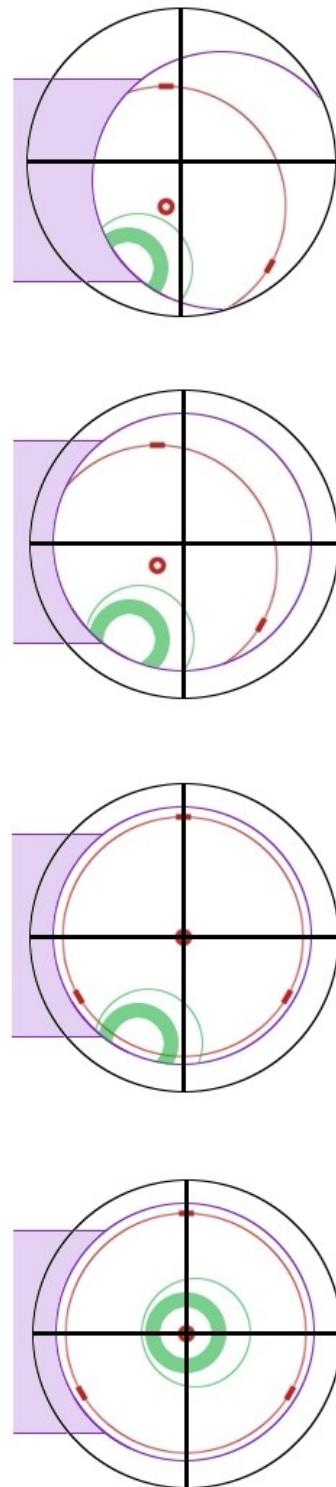


Fig. 111

## Schmidt-Cassegrain

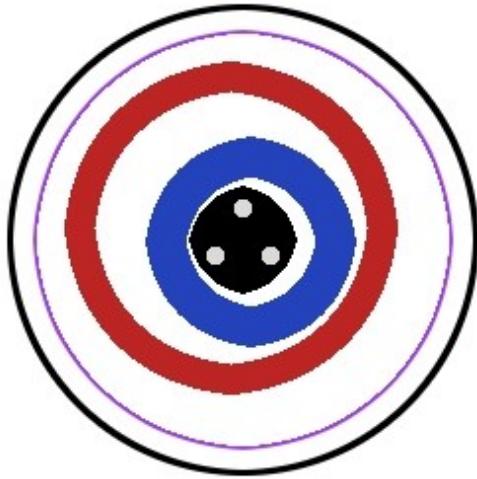


Fig. 112

properly collimated they will be concentric. In an uncollimated SCT the view will be something like Figure 112.

Adjust the three collimation screws in the secondary holder until all of the circles are centred and aligned. When this is done the rough collimation is complete and it is time to head out and find a nice 2<sup>nd</sup> magnitude star. Polaris is a good choice.

Select an eyepiece which gives a good amount of magnification and put the star in the field, centred and slightly de-focused. The star *must* be in the centre of the field and it *must* be returned to the centre of the field after each adjustment.

In an un-collimated SCT the out-of-focus star will show the shadow of the secondary mirror off-centre. Figure 113 shows the star both focused (centre) and either side of focus in an un-collimated telescope.



Fig. 113

With some SCTs collimation may be a two-man job with one person looking at the star and the other adjusting the collimation screws. Bob's Knobs, which are thumbscrews that replace the phillips or hex screws, make collimation simpler and allow one person to collimate smaller SCTs.

The outcome is to have the shadow of the secondary centred to a high degree of accuracy. It takes practice, but once it has been done a few times it becomes second nature.

## Maksutov Cassegrain

Maksutov Cassegrains (MCTs) are much like SCTs except that most have the secondary as only an aluminized spot on the front corrector plate. These will have push/pull collimation screws in the cell that holds the corrector and which allows the collimation of the telescope. Some MCTs do have adjustable secondaries *and* primaries but these are not the norm.



*Image of the Pacman Nebula, NGC281 taken by the author. Captured with a Canon/Hutech 500D mounted on an AstroTech 8" imaging newtonian on a Celestron CGE. Ten 5-minute images at ISO800.*

## Flat Frames

There are seldom times when an optical system put together from many parts works perfectly out of the box. One of the problems that crops up in astro-photography is due to imperfections in the illumination of the sensor. This could be due to vignetting (light being blocked), light falling off at the corners due to the design, dust on the sensor or even pixel non-uniformity.

To remedy the above problems a flat field frame is taken which is then divided into the image frames to boost areas that are under-illuminated. A typical flat frame might look like the Figure 114 which shows fall-off at the corners and a few rings caused by dust motes. Once the images have been processed with the flat frame the imperfections will be gone from the final product.

The flat frames should be taken with the equipment setup as if to image and a new flat frame, or set of flat frames, should be taken each imaging session. Some people develop a library of flats but those won't mitigate the effect of any stray dust that lands on the sensor between sessions.

Flat frames are quite easy to take just after sunset before an imaging session. Of course, the sky will be cloudless which means that it has no visible structure and will generate a flat field when photographed. Point the telescope about 20 degrees from the zenith exactly opposite the point of sunset and shoot a series of pictures. These will be your flat frames.



Fig. 115

The flat frames have to be exposed nicely which means not burned out or too dark. I've found that with my DSLR set at the ISO value at which I'll be shooting the target I adjust the shutter speed to give me exposures that are about 1/3 histogram. With a CCD camera expose for 1/3 of maximum value. A 1/3 histogram is shown in Figure 115. With the stacking software I use (DeepSkyStacker) this seems to give about the best result. Some people place a layer of white t-shirt material over the front of their telescope when shooting flat frames of the sky but I have found that this really isn't needed.



Fig. 116

monitor or perhaps an electro-luminescent panel can be put to use. To use a laptop first set up a white background such as an empty word processing page. Then place the telescope on a tripod or other stand so that the front can be placed flat against the screen with a layer or two of t-shirt material between them. Once setup, a series of as many flats as needed can be shot, again to about 1/3 histogram. Use a 12 V electro-luminescent panel as an illumination source in the same way.

Figure 117 shows how David Haworth of Oregon sets up his Pentax refractor for taking flat frames from his laptop. Notice that he uses a sheet of white plastic between the screen and the telescope as a diffuser instead of t-shirt material (see the Links section).

*So as not to do any damage to the screen, or kill any pixels, don't force the telescope into the LCD .*

For taking flat frames anytime a light box can be built which can be illuminated with an incandescent bulb or other light source. There are as many different designs for light boxes as there are people building them. A good representative example is that which Greg Pyros, an imager from California, has constructed (Figure 116). His light box has inserts or cutouts to allow it to be used with several telescopes and lenses and his website has full plans and a bill of material (see the Links section).

If building a light box is out of the question a laptop or computer



Fig. 117

# Dark Frames

While modern CCD or CMOS cameras are wonderfully low-noise, when shutters are open for long periods of time noise will creep into the images. This can come from internal or external sources and to fight this astro-photographers shoot dark frames. A good starting place for this section is to look at some of the sources of noise.

## Read Noise

Read noise is a fundamental characteristic of any sensor and is generally caused by non-photon-generated electrons read by the camera's amplifiers.

## Dark Current

Sensors build up current whether or not photons are impinging upon them, this is because the sensor is 'hot'. Cooled sensors show less or none.

## Random Photons

This effect is mostly seen in dark areas of images where few photons show up. Photons, being quantum beasts, aren't always predictable. The probability of the arrival of single photons over time is actually a Poisson curve.

## Amp Glow

Amplifier glow is generally manifested in DSLR cameras. The signal that comes from each pixel on a CCD or CMOS sensor is very small. This has to be passed through an analog-to-digital converter and then an amplifier in order to be useful. The amplifiers can become hotter than ambient and add a thermal noise pattern to an image. On Canon DSLRs this showed up as a red area in the lower right corner of an image and resembled sky-glow.

## Fixed Pattern Noise

Fixed pattern noise is commonly seen as 'hot pixels'. These are pixels in a CCD or CMOS sensor that stay on and bright causing white dots on monochrome images or coloured dots on colour images. They don't move (hence 'fixed') from shot to shot. Conversely, a pixel may be dead and cause a completely black dot on either monochrome or colour sensors.

## Random Noise

Intensity changes in pixel output introduced along the electronic path from the sensor through to the amplifier cause this effect.

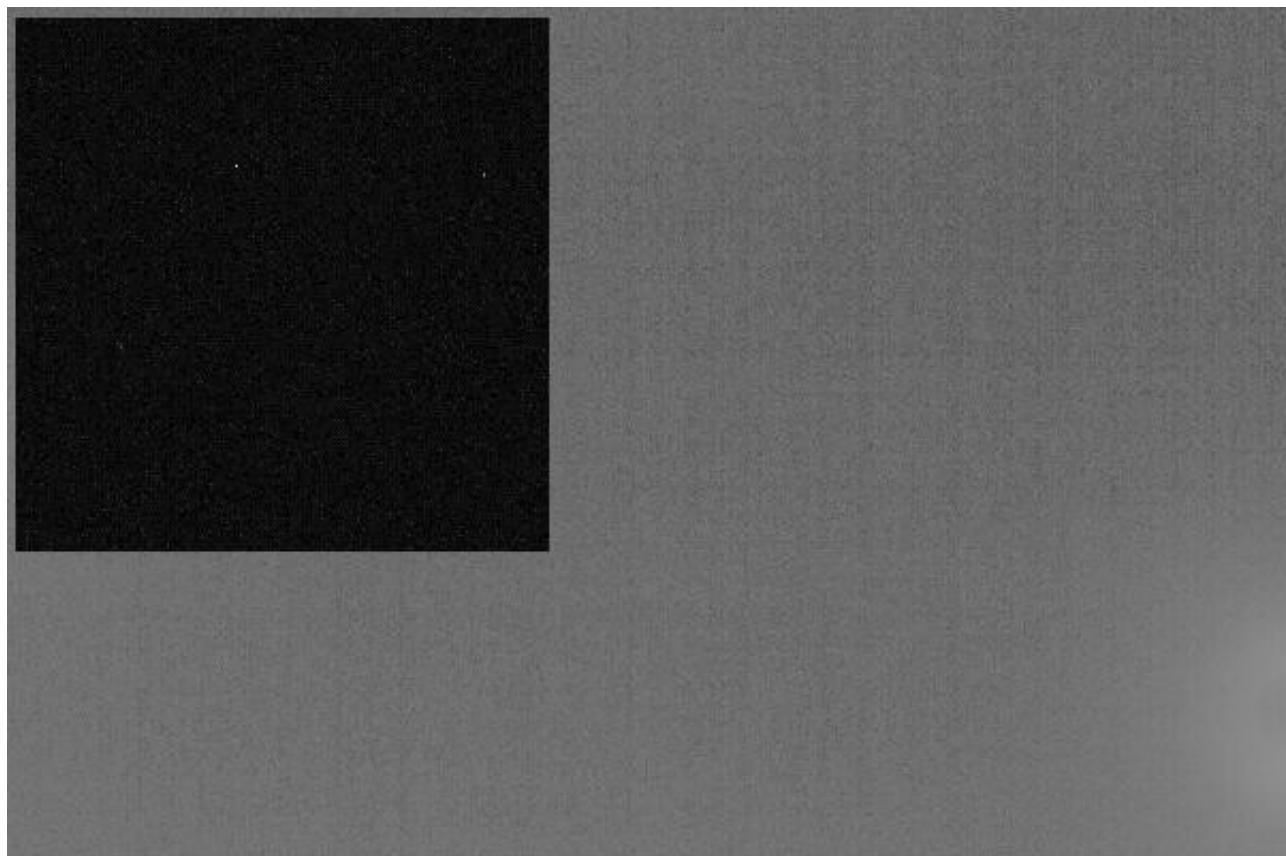
## Banding

This type of noise is mostly seen in CMOS sensors. Horizontal or vertical bands which appear when an image is shot using high ISO values and where the histogram is stretched excessively .

All of the above mentioned noise sources can conspire to reduce the signal-to-noise ratio of your images to the point where the target becomes difficult or impossible to dig out of the muck. Fortunately, today's sensors for the most part display low levels of many of these sources.

Whatever the source in the above list the one solution generally used to fix the problem is to take one or several dark frames. These are taken with exactly the same exposure settings as the image frames but with the shutter closed (CCD) or with a lens or dust cap in place (DSLR). A dark frame will read all of the same sensor noise as the image frames. During processing the noise recorded can then be removed from the actual images.

Figure 118 is an example of a 5 minute dark frame taken at ISO400 with my old Canon 350D. It has been stretched excessively to bring out some of the noise. Notice the amp glow at the bottom right, the banding in the image and, underneath that there are some hot pixels (shown in the inset)

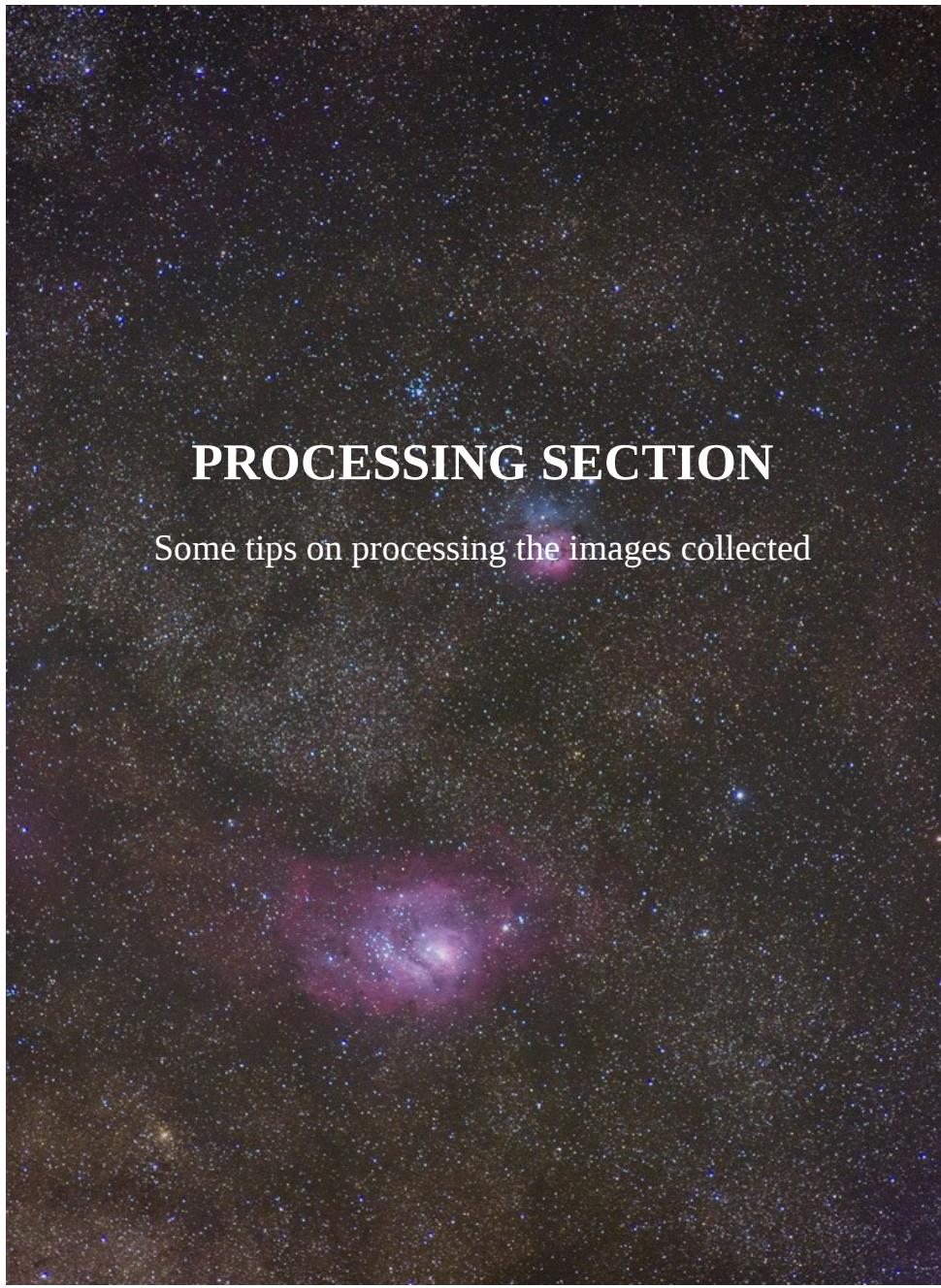


*Fig. 118*

I generally take 5 to 10 dark frames while I'm tearing down my gear after a night of imaging. If the temperature is changing rapidly I'll take my dark frames in the middle and end of the session. A library of darks can be built for different temperatures, but pixels come and pixels go which means that they might not be valid forever.

## **PROCESSING SECTION**

Some tips on processing the images collected



*Lagoon and Trifid by Jon Gunning*

## Stacking Images Using DeepSkyStacker

Once a collection of the light (image), dark and flat frames have been compiled something has to be done with them. The darks and flats have to be processed master images and then subtracted from or divided into the light frames. The light frames then have to be registered and stacked. This can all be done manually using just about any graphics manipulation package, but there is software available that will do all of this work automatically, and well.

The software that will be discussed here, and arguably the most popular freeware stacking package is by Luc Coiffier and is called DeepSkyStacker (DSS). This easy to use package can do all of the stacking and registering needed.

DSS will take as input RAW files generated by most digital cameras along with JPEG, TIFF and FITS. I generally work with RAW data as it has not been altered by the camera's processor and will be free of any artifacts that may come from this type of internal processing. DSS also appears to like RAW files better than the JPEG files my Canon creates.

The DSS work space is in a single window and Luc has eschewed the normal menu list across the top for a column of actions running down the side as seen in Figure 119.

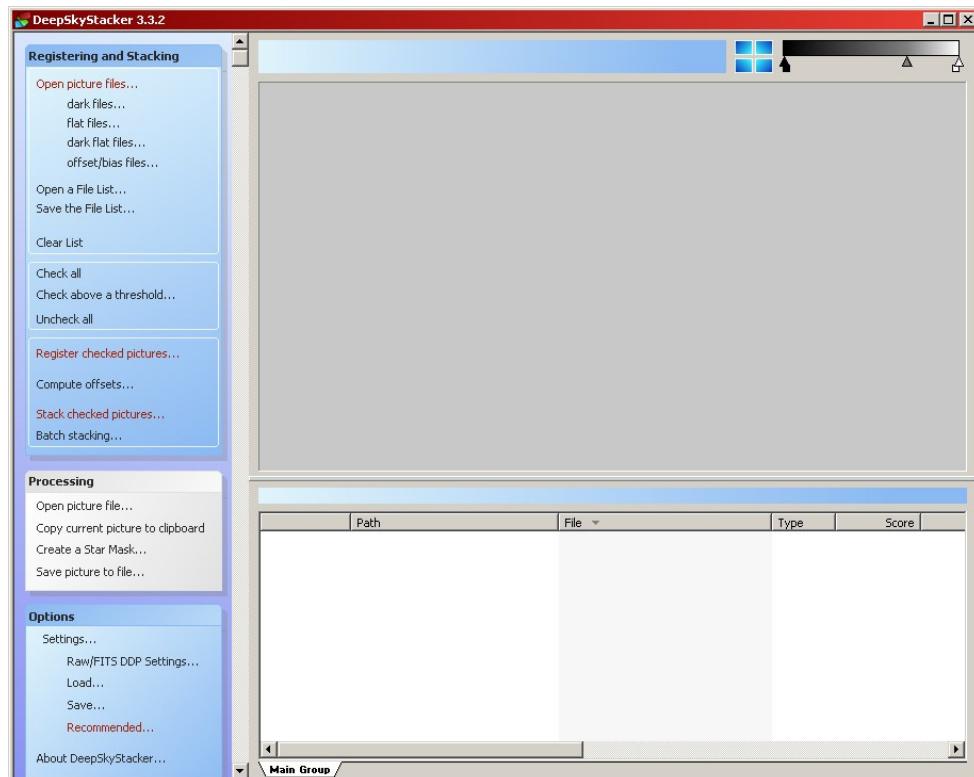


Fig. 119

The work flow in DSS runs generally from top to bottom in a logical sequence, therefore the first thing that has to be done is to load the files to be worked on into the software starting with lights by clicking **Open picture files**. This will bring up a file selection dialog that is used in the standard Windows manner. The same with dark files, flat files, etc.

When all of the files have been loaded the file list can be saved for later use, or if there is already a list saved it can be loaded directly through the **Open/Save a File List** actions. Also, to start fresh a file list can be cleared.

Once the files have been loaded click on the **Check all** item. This will select all of the images in the list for processing. There is a possibility that some images will be removed in the future, but for now DSS has to have access to all of them.

Once the images have been checked right click on the first light image and check 'Use as reference frame'. This will be the image that DSS checks each succeeding image against.

From this point DSS has to check each image and determine several properties. It will calculate how far from the reference image each is in X and Y axes and in rotation. It also checks for the roundness and focus of stars and will display the FWHM for each image and assigns each a quality value.

To do this, with all of the files checked click on the **Compute offsets** action. The work being done will take some time but when it is complete the file list at the bottom of the window will be fully populated,

as partially shown in Figure 122. At this time the image attributes can be inspected line by line and a decision made as to which images will be included in processing the final output image or discarded.

As can be seen each image in this list is 'drifting' in X, Y and rotation from the reference frame; most probably due to differential flexure. Most light frames only deviate from the previous one by a pixel or two but there may be a few large jumps in the list. The files with the large jumps will be too heavily smeared to use so they should be discarded.

Even if the stars aren't blurred the image may be out of focus or some thin cloud may have partially obscured the light. This will show up in the Score column by showing a number that is far below the average. If I see a problem I usually open the image in Digital Photo Professional to check it out.



Fig. 120

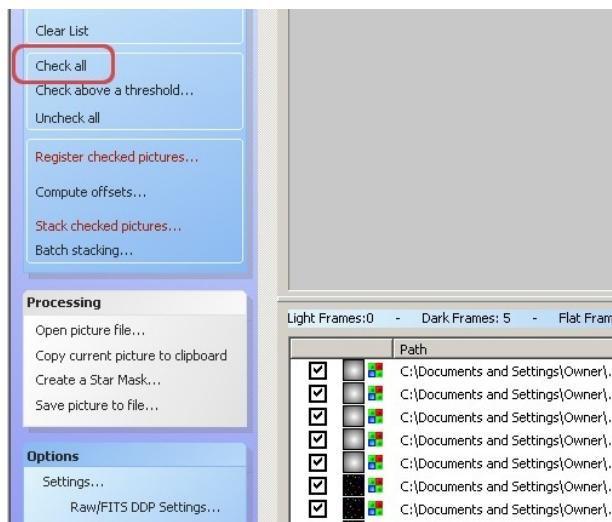


Fig. 121

h	File	Type	Score	dx	dy	Angle	Date/Ti
Documents and Settings\Owner\...	MasterFlat_IS0800.tif	Master ...	N/A	N/A	N/A	N/A	10/10/2010 7:33:4
Documents and Settings\Owner\...	MasterDark_IS0800_420s.tif	Master ...	N/A	N/A	N/A	N/A	11/22/2010 8:20:1
Documents and Settings\Owner\...	IMG_0015.CR2	Light	0.00	NC	NC	NC	8/11/2010 12:05:2
Documents and Settings\Owner\...	IMG_0014.CR2	Light	0.00	NC	NC	NC	8/10/2010 11:58:1
Documents and Settings\Owner\...	IMG_0013.CR2	Light	0.00	NC	NC	NC	8/10/2010 11:50:5
Documents and Settings\Owner\...	IMG_0012.CR2	Light	3418.96	-20.87	10.90	-0.12 °	8/10/2010 11:42:2
Documents and Settings\Owner\...	IMG_0011.CR2	Light	3993.66	-19.25	8.62	-0.11 °	8/10/2010 11:35:0
Documents and Settings\Owner\...	IMG_0010.CR2	Light	6541.67	-16.84	7.37	-0.09 °	8/10/2010 11:27:4
Documents and Settings\Owner\...	IMG_0009.CR2	Light	6730.58	-12.98	6.94	-0.07 °	8/10/2010 11:20:3
Documents and Settings\Owner\...	IMG_0008.CR2	Light	5202.47	-7.65	6.92	-0.06 °	8/10/2010 11:10:4

Fig. 122

Once the file list had been pruned it is time to register and stack the images which is done by clicking on the Stack checked pictures item. Now it is time to go have a coffee, watch a movie or something else that will take up time as it can be a lengthy process. DSS automatically combines your dark and flat files into a master dark and a master flat and will use these in further processing. They are saved in the directory that they were chosen from.

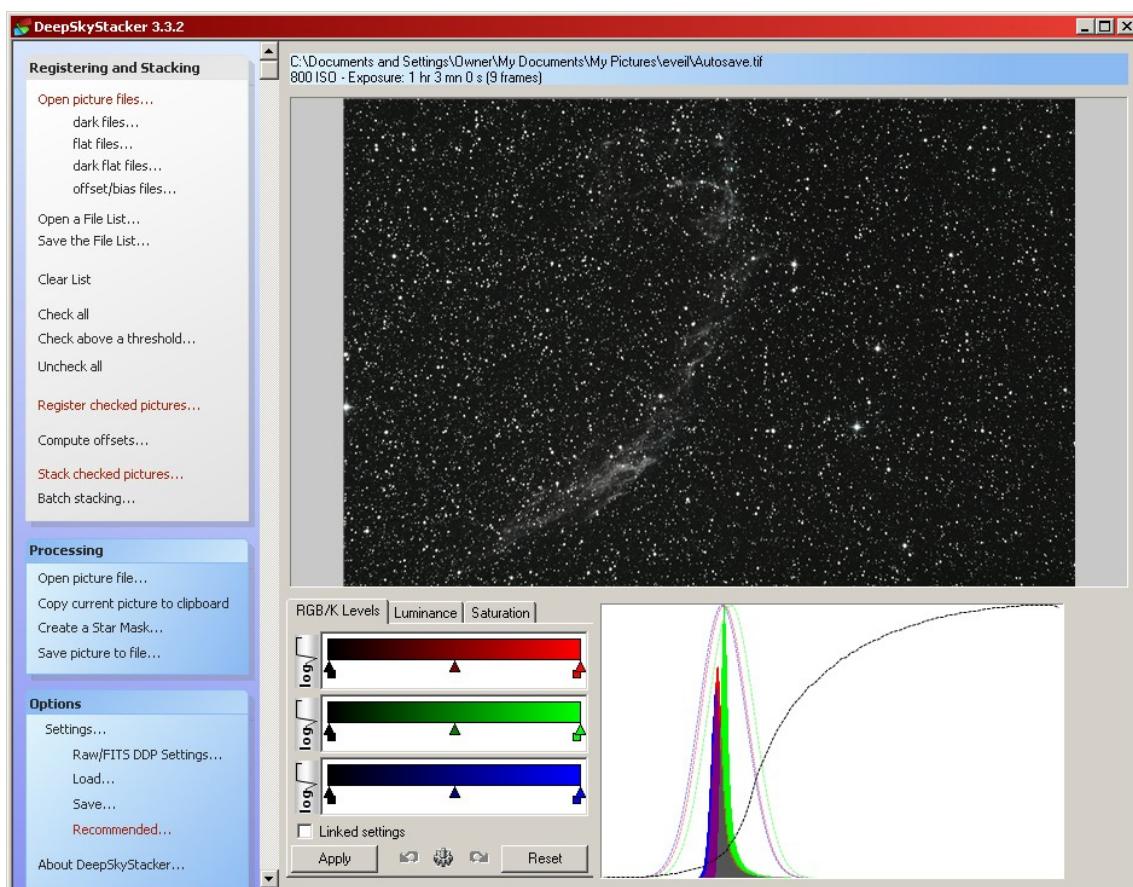


Fig. 123

Now stacking is finished and DSS displays the final image for processing in DSS. I generally don't as I prefer to use PhotoShop or the GIMP.

The final image is saved in the same directory as the light frames were and is called Autosavexxx.tif. The xxx are numbers 001, 002 etc. as there may be more than one in the directory. They are in the format of a 32-bit TIFF image. To save as a 16 or 32-bit TIFF or a 16 or 32-bit FITS file click **Save picture to file**. I generally use 16-bit images and knock them down to 8-bit later.

I use Canon RAW files exclusively for all my images: light, dark or flat. To configure how DSS uses RAW or FITS files click on **Settings->Raw/FITS DDP settings** to bring up the settings for that file type.

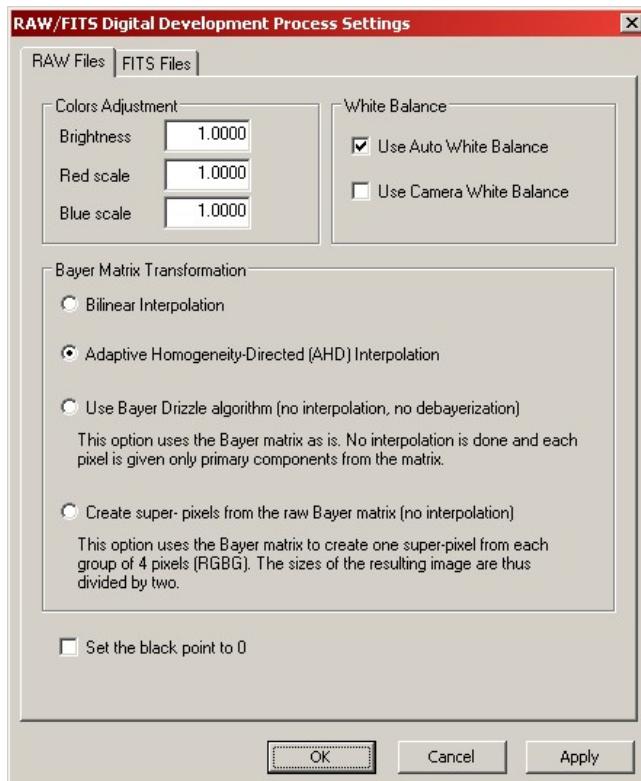


Fig. 124

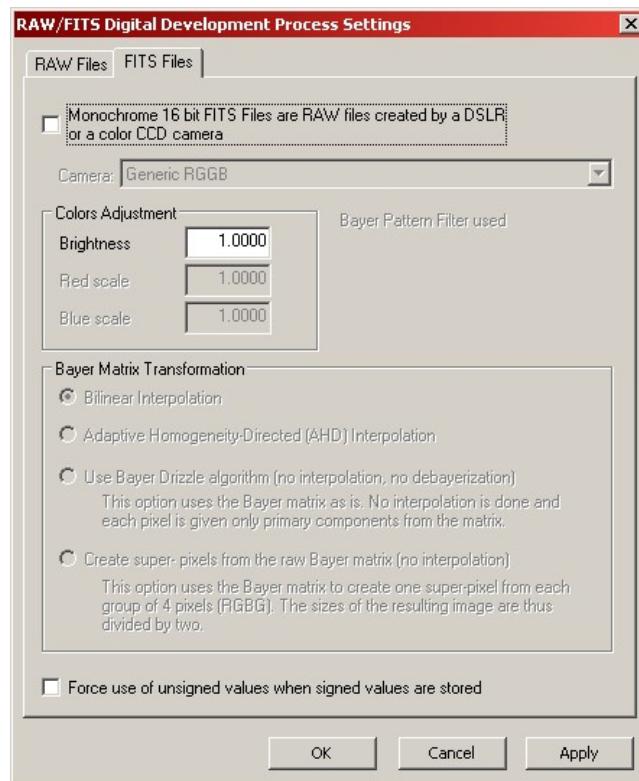


Fig. 125

I've found that with my two Canon cameras that nothing has to be changed in the RAWS dialog. The only thing I can think of that I might play with is to use the white balance from the camera as my Canon has been modified and I do use a custom white balance.

DSS can also provide a lot of recommended settings based on its analysis of the file list. These are accessed by clicking on **Settings->Recommended**. The dialog in Figure 126 shows a list of things that DSS has noticed and what it recommends to do. To do it just click on the underlined link.

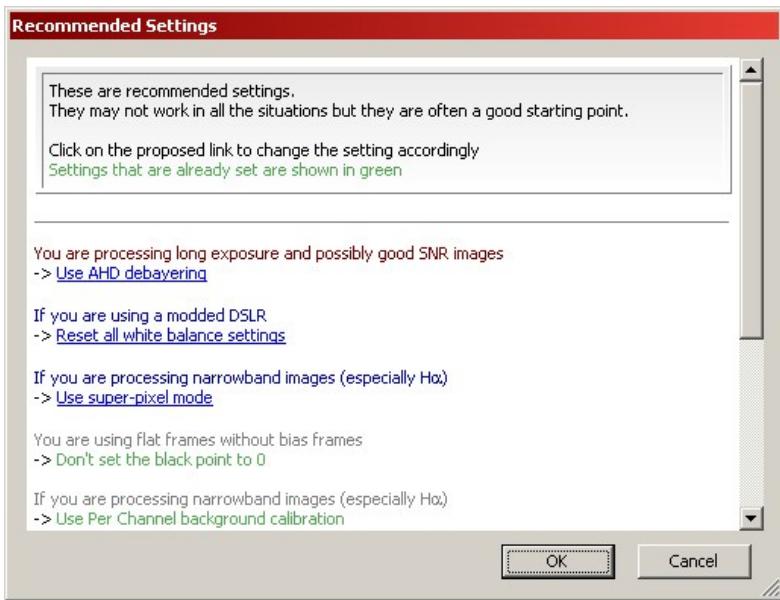


Fig. 126

software, should be joined. There is also on-line documentation on every option.

To download the latest software or to go over the documentation the URL is below.

<http://deepskystacker.free.fr/english/index.html>

Of course, access to all of DSS's multitude of settings is available by clicking on **Settings** then selecting either **Register** or **Stacking**. **Register** brings up the star detection dialog with a slider. Selecting too few or too many stars can alter the registration process. I leave mine at around 40%.

To have access to the rest of the settings that DSS has available select **Stacking** from the **Settings** list. This opens up a multiple-tab dialog that allows adjusting just about everything in the software. I leave most things at default but have tested a few of them, generally to my chagrin.

DSS has quite an active Yahoo! group which, if one is going to use the

## Stacking Images with IRIS

IRIS is a powerful image registration, stacking and processing software package that, unlike DeepSkyStacker will work perfectly in a virtual PC and is available to be downloaded free. This software, written by Christian Bull, does not have the ease of use exhibited by DeepSkyStacker but it is much more versatile, especially in the area of pre-stack processing.

IRIS is also fully scriptable allowing for automation to be built-in if needed. This section will only cover the process of registering and stacking a set of images.

IRIS works either with a typical Windows set of menus and icons and also has a 'command window' where internal processing commands can be typed in to perform various tasks. On startup of the

software the command-window should be opened which is done by clicking on the icon indicated in Figure 127. The command window shows a > prompt (Figure 128). Commands are typed in and executed by hitting the ENTER key.

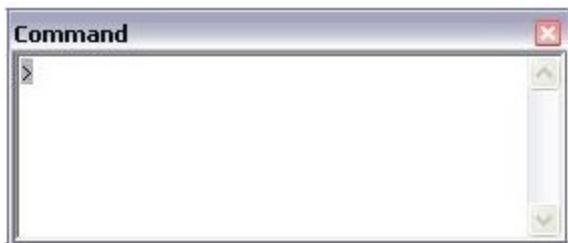


Fig. 128

IRIS wants (requires at times) a full set of images: light, dark, flat and offset. Other than the light frames these can be 'faked' if there were none taken. The creation of

a 'pseudo-offset' image will be described as I had none on hand. The rest of the images used in this document are from an actual imaging run.

IRIS works internally with PIC, FTS or FIT files and any images taken that aren't in either of these formats will have to be converted. Lights, darks, flats, etc. should all be converted separately. The picture type that IRIS will use, along with some useful directories, should be set on start-up by using clicking on the **FILES->SETTINGS** menu item. This will open up a configuration window (Figure 129) where the needed values can be entered. These are saved from one processing run to the next.

There is no difference to the software which type is selected. I use PIC for no other reason that it is what I selected when I first started playing with IRIS and I haven't seen the need to change. Also, an empty directory to be used as the working path should be set. This is



Fig. 127

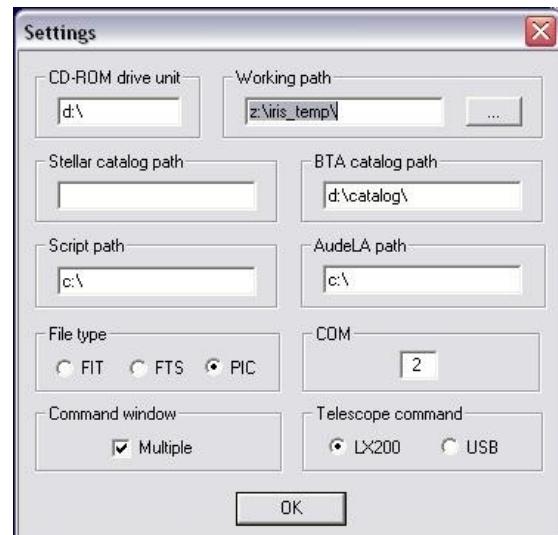


Fig. 129

where IRIS will store any intermediate or temporary files. After a processing session this should be cleaned out.

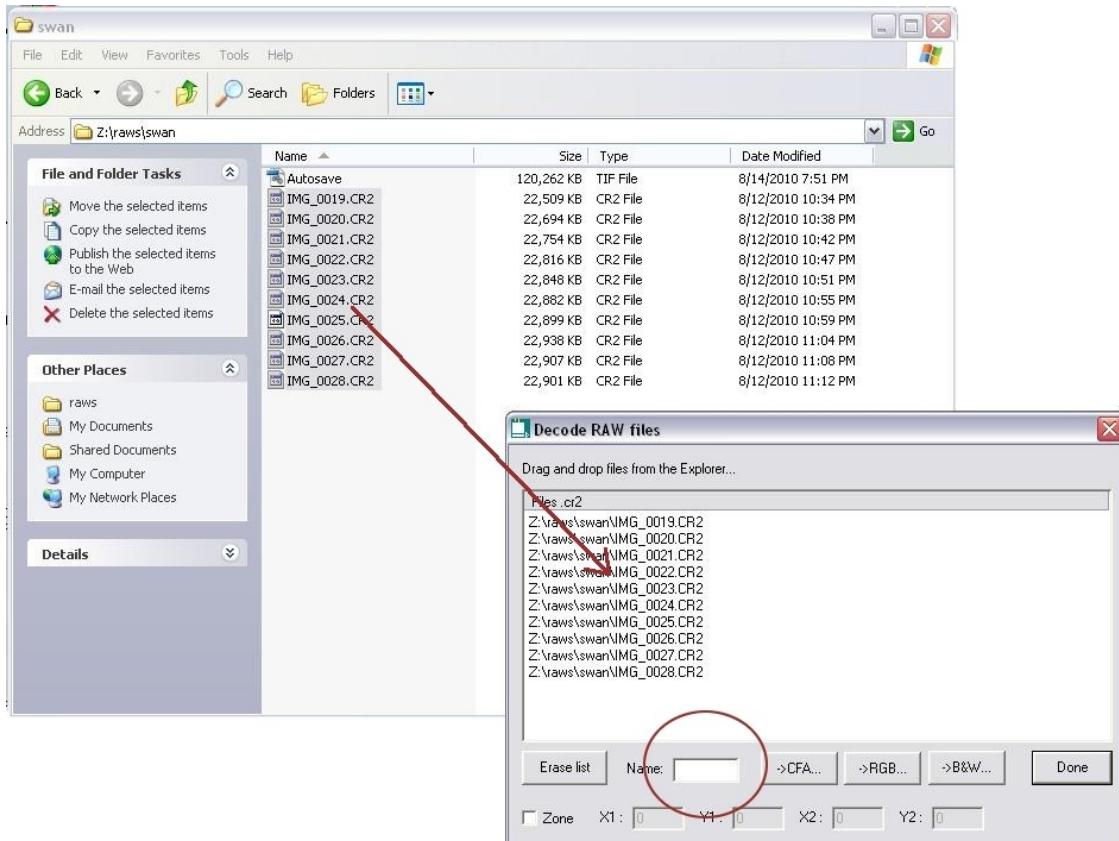


Fig. 130

IRIS can work with the RAW files from most digital SLR cameras along with most formats generated by other cameras and software. Before it can work with the RAWs though they must be converted to one of the file types set forth in the configuration dialog.

IRIS uses 'generic' names in its processing for both input and output. As it normally is given a sequence of images it will automatically append a number onto any generic name. In the work flow the generic output name is generally the next task's generic input name.

To start file conversion select **DIGITAL PHOTO->DECODE RAW FILE** from the menus. This will close the main IRIS window and open a **Decode Raw Files** window. Next open up a Windows Explorer file list for the directory where the RAW files reside. Drag the required files into the decode window (Figure 130). Once the **Decode Raw Files** list is populated put a generic name for converted files in the 'Name' box (circled) and then click the CFA button. I suggest using 'light-' for the light frames generic name, 'dark-' for the dark frames and 'flat-' for the flat frames. For example, the first light file, IMG\_0019.CR2 will be renamed to light-1.pic (or FIT etc.) When the CFA button is clicked a progress dialog will open. Repeat the procedure for darks, flats and offset files.

Once all of the files have been converted master dark, master flat and master offset files have to be created. I don't generally shoot offset files but IRIS wants one so a 'pseudo offset' has to be created which can be done using the tools available in the program. To create the file one of the light frames is loaded into IRIS, filled with the value 0 (black) and saved. In the command window the following commands are entered:

```
load light-1
fill 0
save offset
```

The creation of a master flat and master dark (and a master offset if you've taken the frames) are pretty much the same procedure. The sequence to create a master dark starts with selecting the menu item **DIGITAL PHOTO->MAKE DARK** which will open a dialog window (Figure 131). Enter the generic name of the dark frames (dark- in our example) and set the number of darks that were taken. The *Offset* box should already have 'offset' entered, which is the name I chose for the pseudo-offset file. Clicking *OK* will bring up a progress dialog. The same procedure is used for flats, **DIGITAL PHOTO->MAKE FLAT FIELD** (Figure 132) and offset **DIGITAL PHOTO->MAKE OFFSET**.

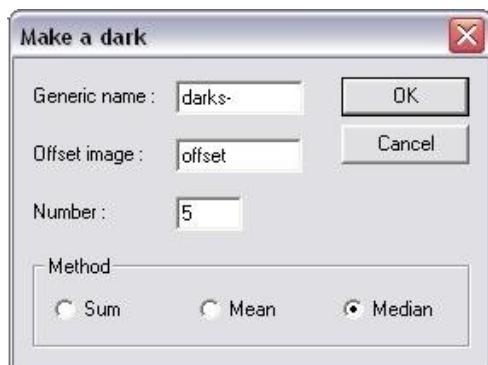


Fig. 131

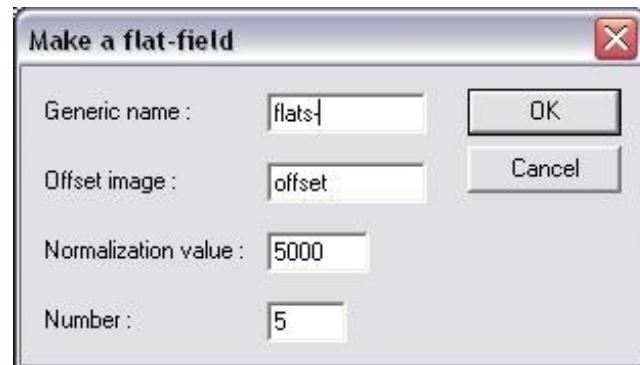


Fig. 132

The master files are not automatically saved by IRIS. When the task of making a dark or making a flat-field is done a save command must be typed into the command window to save the image. For the dark type '**save dark**', for the flat type '**save flat**' and for the offset (if you made one) type '**save offset**'.

With a master dark file on hand it is now possible to create a cosmetic file. This is a list of sensor defects that IRIS uses to repair an image. The simplest way to create the list is to go to the command window issue the following commands:

```
load dark
stat
find_hot cosme THRESHOLD
```

To determine the value of THRESHOLD that should be used look in the Output window and calculate

$$\text{Mean} + (16 \times \text{Sigma})$$

These will load the master dark that was created earlier, then find any pixels that have a value over a threshold of 300. The positions of these will then be stored in a file called 'cosme.lst' for use in the next step, pre-processing.

There are now a full set of images ready for further processing by IRIS. The first thing that has to be done with them is to pre-process the light images with the master flat, master dark and master offset files. To start this one of the light frames has to be loaded by going to the command window and typing:

### load light-1

Now use the mouse to create a box somewhere in a star-sparse area of about 200 to 300 pixels (Figure 133). This is done by clicking in a dark location and dragging the mouse to create the needed box. This zone is used by IRIS to compute the optimal dark. Next the **DIGITAL PHOTO->PREPROCESS**

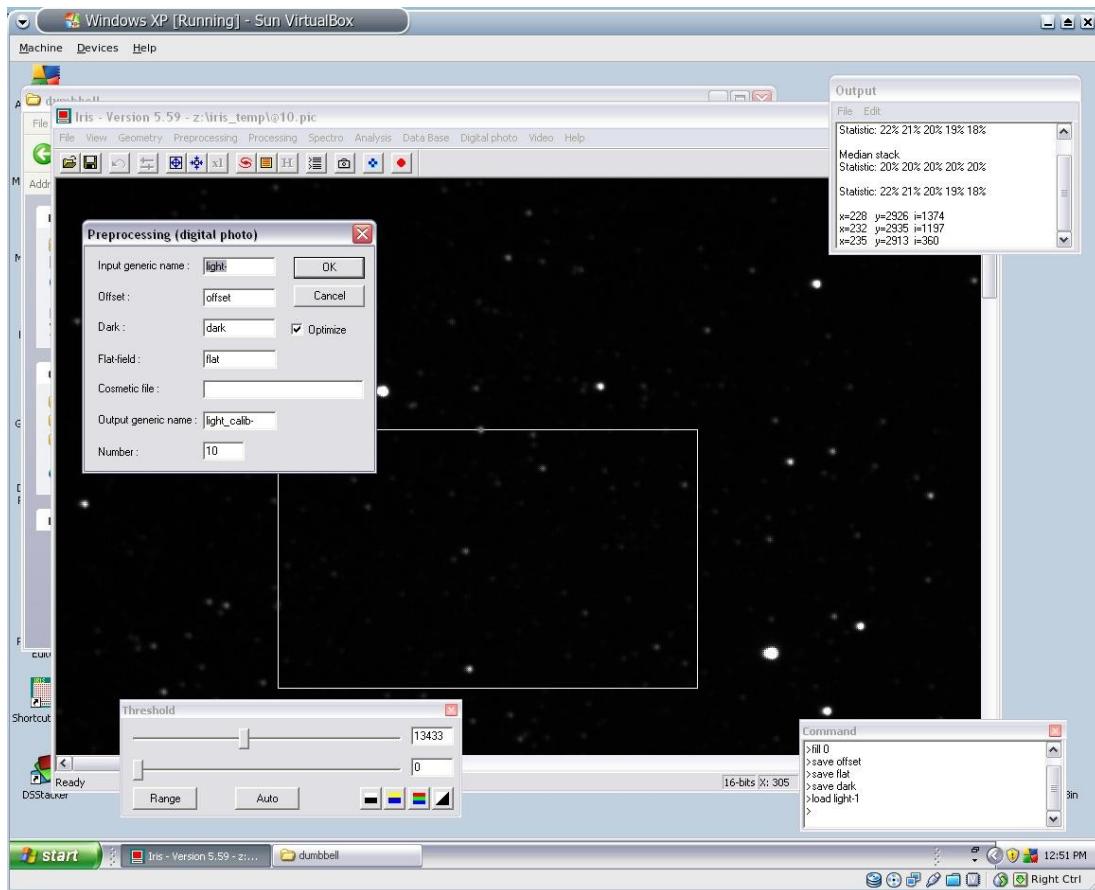


Fig. 133

menu item is selected which opens a dialog box. Fill in the generic names of the light images, master dark, master flat and master offset. These last three are the names given earlier when they were created: flats, darks and offset and check the *Optimize* check box.

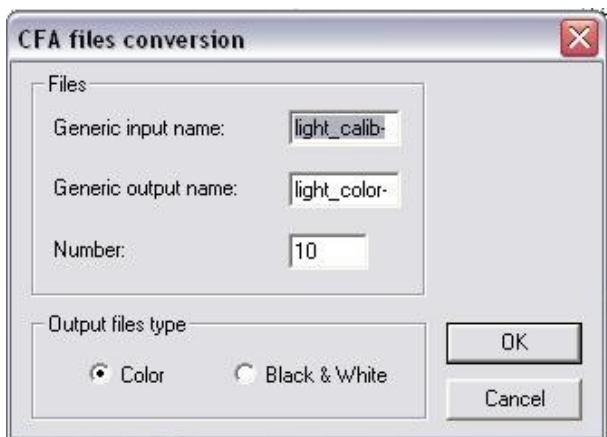


Fig. 134

Converting to colour takes as input the calibrated files we've called 'light\_calib-' and outputs colour files that we'll call 'light\_colour-'. The number entry should be correct but make sure that it is and in the bottom row check the 'Color' radio button..

With the files now ready to register and stack any further pre-stack processing can now be done. IRIS can do things like applying an unsharp mask or white balance adjustment to the whole sequence individually. For now select **PROCESSING->STELLAR REGISTRATION** from the menu list. This will open another dialog box (Figure 135).

In this dialog box enter the generic input name of the colour files (in this case light\_colour-) and enter a generic output name. Here I've used 'light\_registered-'. Again, IRIS may have the correct number entered but it is a good idea to check this and correct it if needed.

There are several methods available some of which are faster and less accurate than others. I always use the '*Global matching*' method which looks at all the recognizable stars in the image. The transformation that I use with this is '*Quadratic*'. This means that it will take some time to register the images so once 'OK' is clicked it might be a good time to go for lunch. No progress bar is provided here but the IRIS title bar shows which file is being processed.

In the bottom entry box titled 'Number' should be the number of light images that will be processed. Clicking OK starts the pre-processing.

Once the images have been pre-processed it is time to convert them into a colour format if they are the product of a DSLR or other colour camera. The PIC or FIT images that IRIS has been working with up until now are monochrome and they should be in their colour version to stack. To convert to colour select the **DIGITAL PHOTO->SEQUENCE CFA CONVERSION** menu item which will open up the dialog box shown in Figure 134.



Fig. 135

With the images registered there is only a single major task left which is to stack the registered images. Again in the **PROCESSING** menu select the **ADD A SEQUENCE** item (IRIS doesn't call it stacking but calls it adding). This will bring up the last dialog box (Figure 136) where again a generic input name and the number of images are asked for. The input name will be the output of registering, or 'light\_registered-' and once again the number of images is 10.

The '*Normalize if overflow*' check box will, if checked, tell IRIS to adjust the stacked image's brightness if stars become saturated. Below this are the various stacking methods that can be used which are:

### **Arithmetic**

Simple addition of all pixel values determines the output pixel value

### **Median**

The median value of all pixel values determines the output pixel value

### **Min-Max rejection**

The lowest and highest values are thrown out and the remainder added.

### **Adaptive weighting**

A robust average based on Stetson's Artificial Skepticism Stacking algorithm (I like this one)/

### **Sigma clipping**

Pixels that deviate from the median the most will be rejected in the final output. The rest will be added.

### **Sigma median**

Similar to Sigma clipping but a rejected pixel will be replaced by the median and added with the rest.

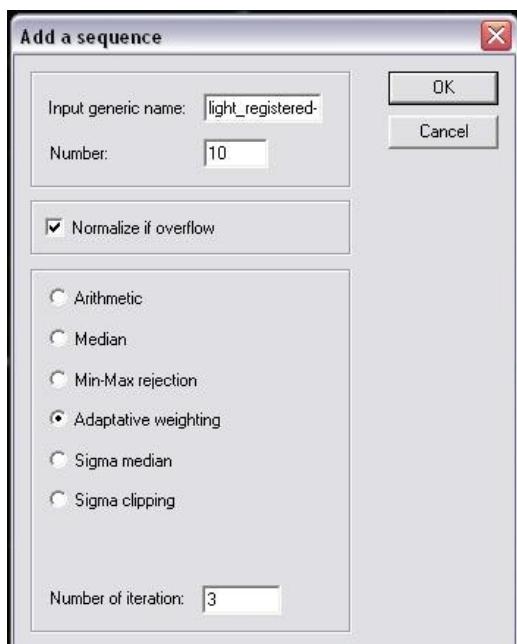


Fig. 136

If the '*Number of iterations*' box is un-greyed (depends on the radio button for type of stack selected) then the number of iterations can be entered. I've found that three to five is about right.

When the stack is finished the final image will be displayed in the IRIS window.

If any post-processing is to be done such as the removal of gradients or noise then save the image as a temporary file. The command to do this is:

**save temp**

If all of the remaining processing is to be done in an image manipulation package such as PhotoShop or the GIMP then the final image can be saved in one of several formats by selecting **FILE->SAVE** which acts much like any other Windows application.

## Some IRIS Procedures

### Gradient removal

If there is a noticeable gradient in the image background such as may be present if shot from a light polluted area then some steps should be taken to remove the gradient and any high-frequency non-uniformities.

To start removal of any gradient in the processed image first type the following into the command window.

```
save temp  
bg
```

In the Output window IRIS will print the level of the background which I'll call BGVALUE. Next the following commands are issued:

```
bin_down BGVALUE  
save mask
```

To see the results of the above the *Auto* button in the threshold windows is clicked on and then the image zoomed out. If the background on the mask created doesn't look like even then re-load the image using:

```
load temp
```

and re-run **bin\_down** with a new BGVALUE adjusting it up and down until the mask looks correct. Always re-load the temporary image before each change in BGVALUE and when the mask looks correct save it with the **save** command..

When the mask looks right clicking on **PROCESSING->REMOVE GRADIENT (POLYNOMIAL FIT)** will bring up the dialog window in Figure 137. Various combinations of values here can be tried but selecting 'Medium' for both *Background detection* and *Fit precision* generally works. Check *Use a mask* and enter the name 'mask' (which you created above) in the entry box. Also, *Balance background color* should be selected.

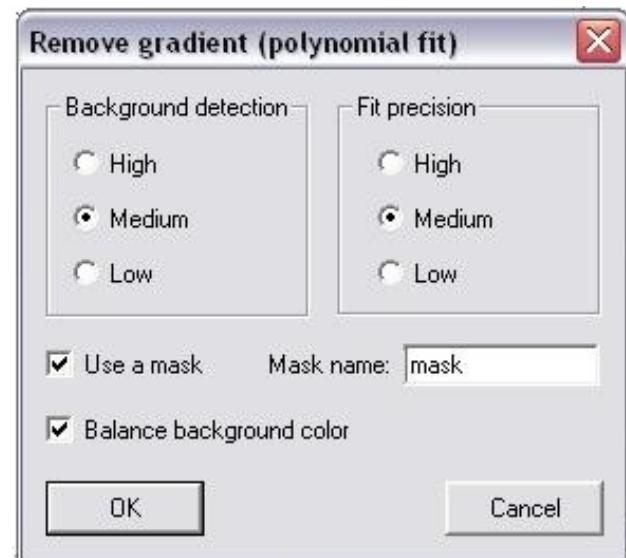


Fig. 137

After the dialog box is executed IRIS will analyze the image and subtract any gradient. A non-automatic method would be to type the following commands into the command window.

### **save temp**

The image should now have a very even background with very little, if any, variation.

## **Noise removal**

To remove noise in IRIS using an adaptive filtering schema on a 3x3 or 5x5 pixel matrix use the command

### **af3 [COEF] or af5 [COEF]**

Where COEF is between .1 and 5. Increasing the COEF value will make the noise suppression stronger.

There are many other functions that can be performed in IRIS, some which work only on the image that is loaded in memory and others that can be done to a whole sequence. The Processing menu items are shown in Figure 138.

Blur filters, wavelet filters and enhancement functions such as unsharp masking (which is one of the functions that can be run on a sequence) are available from this menu. Many other functions are available as typed in commands.

IRIS has the ability to run command scripts which means that if there are a sequence of commands that are commonly used they can be stored as a script file and run from the command window by typing in:

### **run command\_file\_name**

The final image is not saved so this has to be done manually. I generally save my final files as TIFF files and do it using the **FILE->SAVE** menu item which brings up a Save as dialog (not 'normal' but

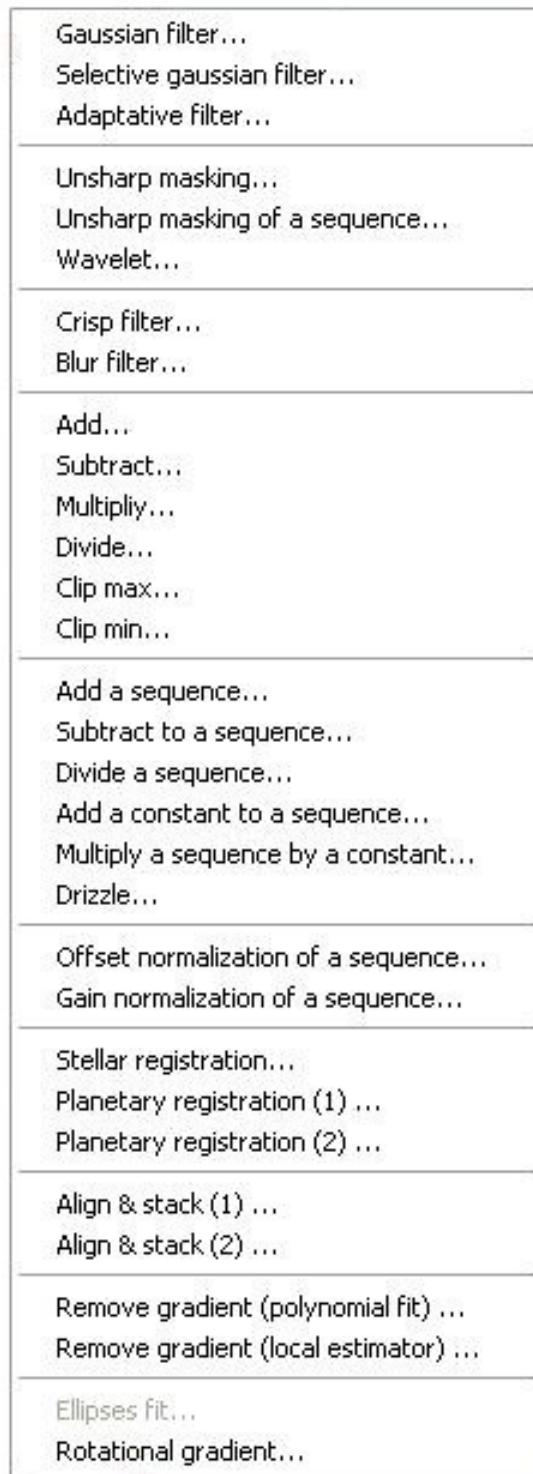


Fig. 138

this is what it does) which allows a file name and file type to be selected for saving. The final image is now ready for PhotoShop, the GIMP or whichever software will be used.

IRIS can be downloaded from:

<http://www.astrosurf.com/buil/us/iris/iris.htm>



*An image of NGC6946 taken by the author with an AstroTech 8" Imaging Newtonian and a modified Canon 500D. Ten 5-minute images at ISO800.*

## Processing Images Using the GIMP



Fig. 139

16-bit image will be an issue then the initial histogram stretching can be done in just about any other image processing software. The image returned to me by DSS is shown in Figure 139.

The generated image is generally very dark and little detail is visible. Don't worry, all the detail that one could want is there, it's just waiting to be dragged out by main force.

Initially I spend my time stretching the histogram. Looking at the histogram in this image you will see that there is only a large spike far to the left side. What we want to do is to move that hump in the middle of the histogram and spread it out so that it covers most of the horizontal axis.

To do this I make use of Layers and Curves. Levels changes the image linearly and Curves makes non-linear changes. Initially I select **Colors->Levels** from the menus which brings up the dialog in Figure 140.

If there is a G2 spectral class star in the image I would set the white point (the pointer under the far right edge of the histogram) be clicking on the right-hand pointer below All Channels then clicking on the G2 star. Why? Our sun is of that spectral class

After an image has been registered and stacked it will need some processing to bring out all of the detail that has been captured. In this section I will process an image of M27 that was captured with an AstroTech 8" f/4 Newtonian and modified Canon 500D camera. I will be using the GIMP under Linux which works the same as the Windows version. Both are free. In PhotoShop the routine is about the same.

The output of DSS is a 16-bit TIFF image but the GIMP can handle only 8-bit TIFF images. If not being able to handle the full

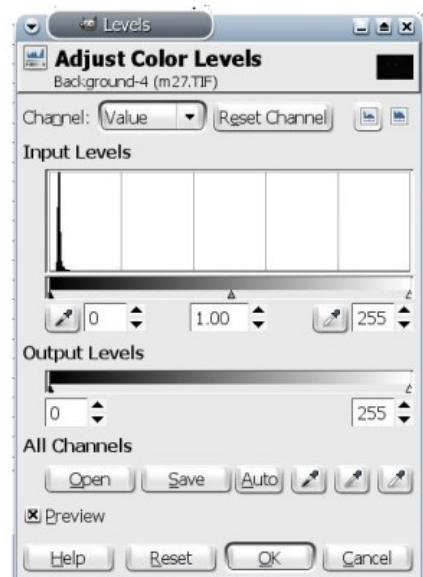


Fig. 140

and it gives us our definition of 'white' as a consequence of the evolution of our eye. If there are no recognizable G2 stars, as in the image I'm working with here, I just leave the white pointer where it is.

After setting the white point I stay in the the Levels dialog. Notice that the histogram is packed tightly against the left side of the chart. Not much wiggle room there but I'll grab the pointer under the left side of the histogram and move it slightly right to the left edge of the spike and then grab the centre pointer (grey point) and move it slightly to the left (just slightly) to bring out some brighter detail.

Generally I don't suggest playing with the grey point so early in processing but this image called for it. Once the levels look good then I'll move on to Curves.

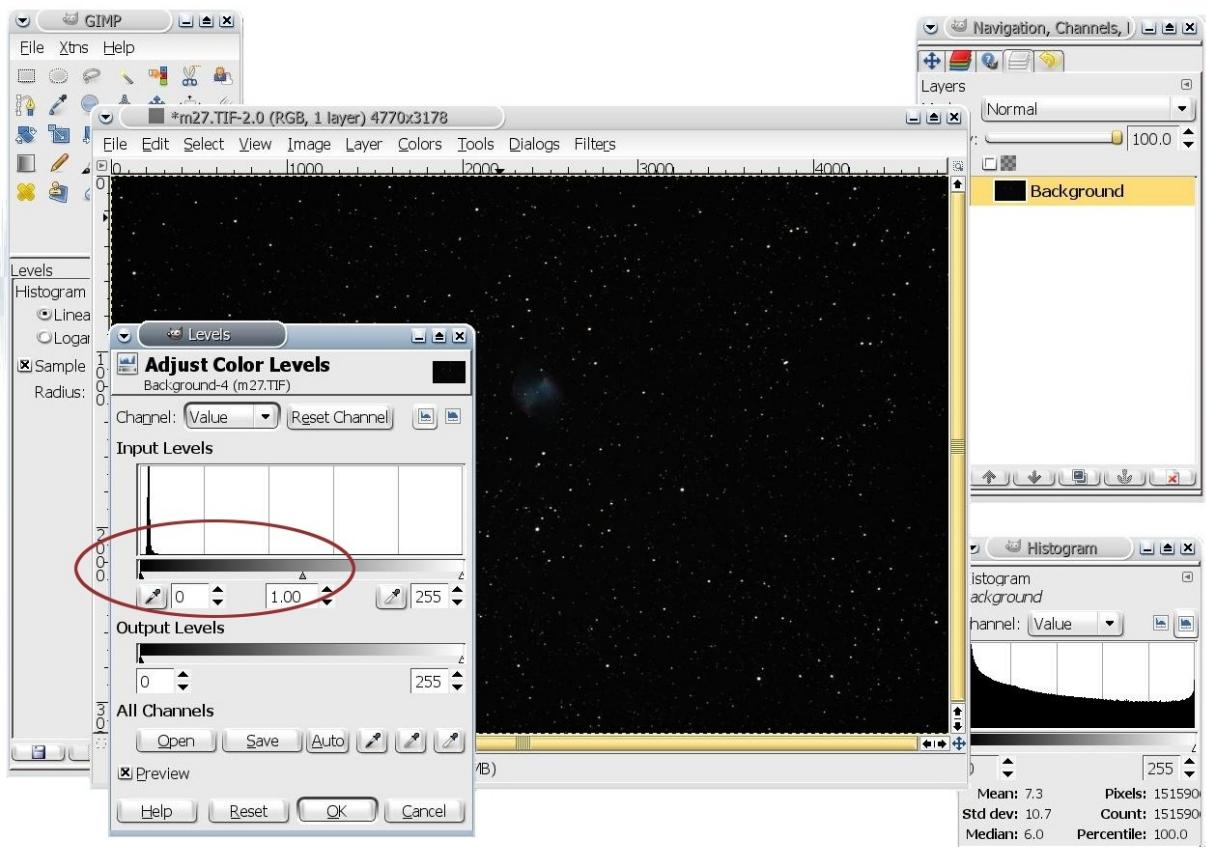


Fig. 141

The next step is to select **Colors->Curves** to open the Curves dialog. Again I'm be working with all channels so 'Value' is shown in the Channel drop-down.

I'm going to stretch the histogram using small actions so I grab the middle of the curve shown in the chart and drag it up and to the left about one box. The result of each action is shown as it is being done so more or less may be used but I've found that many iterations using a small amount of change in Levels and Curves is better than making large adjustments.

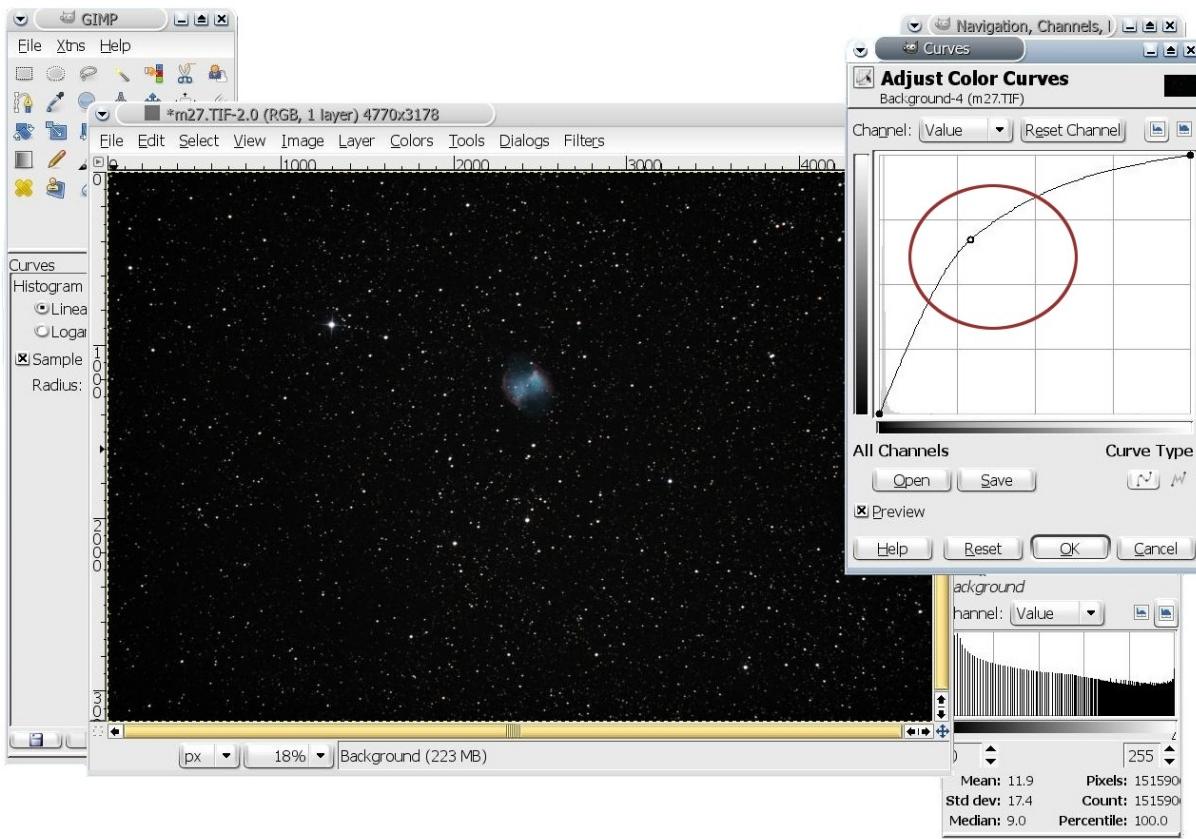


Fig. 142

Already I'm seeing some of the detail and colour starting to emerge from the image.

Now that I've adjusted the Curves I go back to Levels. Notice that the histogram has moved right and has started to spread nicely. Once more I grab the left hand pointer and move it to the left side of the bump in the histogram. This time I'm not touching the centre pointer as the grey point seems fine.

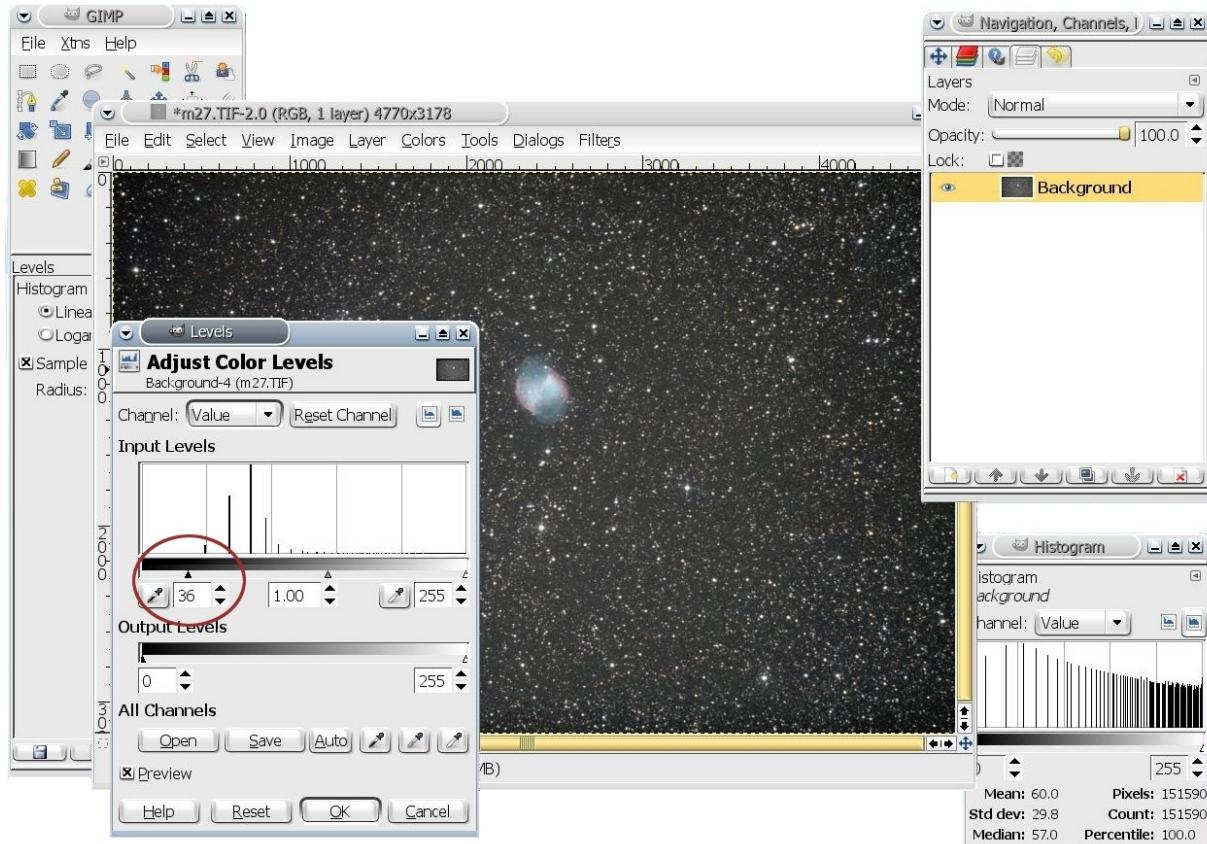


Fig. 143

From Levels I go back to Curves. Notice the pattern here. Levels-Curves-Levels-Curves until things look almost right. The last adjustment I'm doing is in Curves where I'm using a flat S-shaped to tweak the dark and light output to where I want them before moving on. M27 is now fairly bright and there are a lot of field stars around. I want it framed better so it's time to crop.

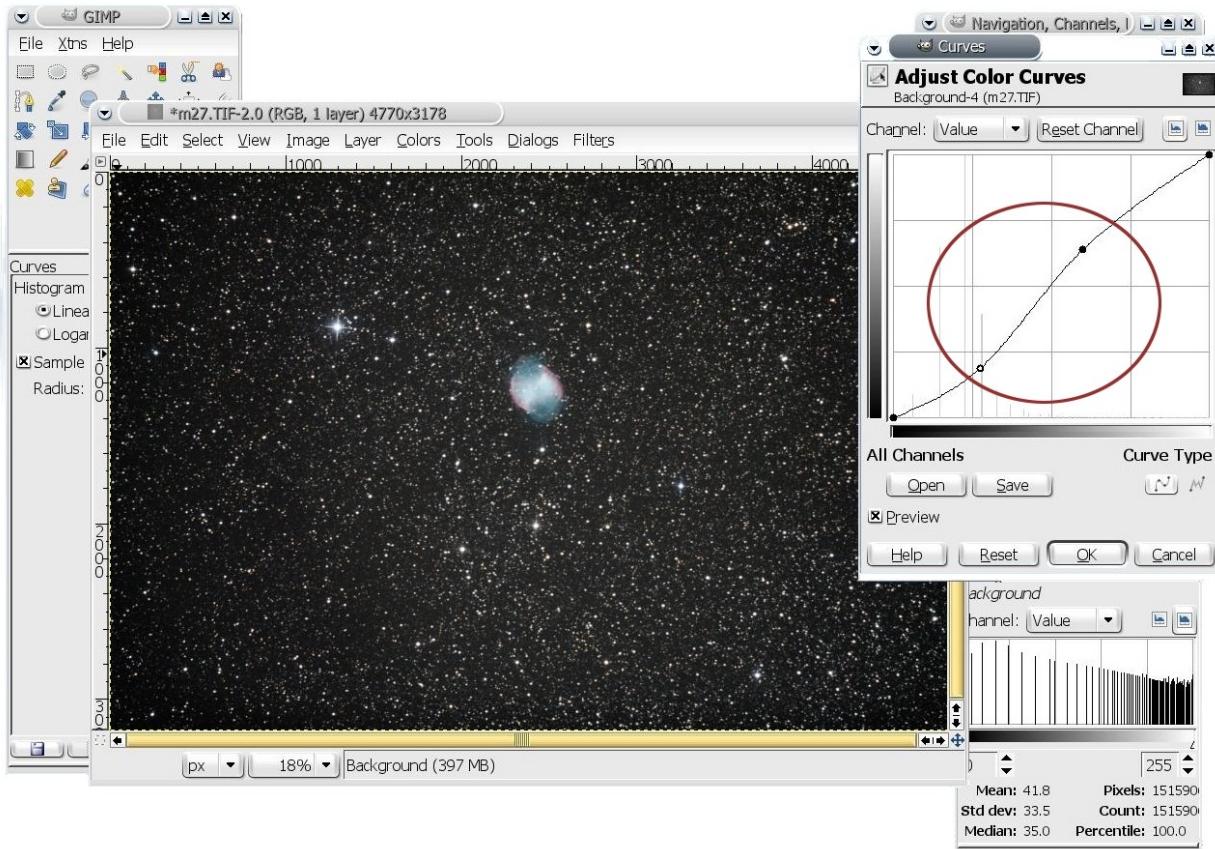


Fig. 144

I select **Files->New** and create a new window of 2400x1600 pixels. Then, in the original image I select **Select->All** and **Edit->Copy**. This grabbed the whole original image which I then paste into the new window using **Edit->Paste**.

Using the 'Move' tool (crossed arrows) I drag the image to where I wanted the framing to be then select **Layer->Anchor Layer** to set it.

The next step I take is to bring the colour to where I want it so I select **Colors->Color Balance** and tweak the Shadow, Midtones and Highlights.

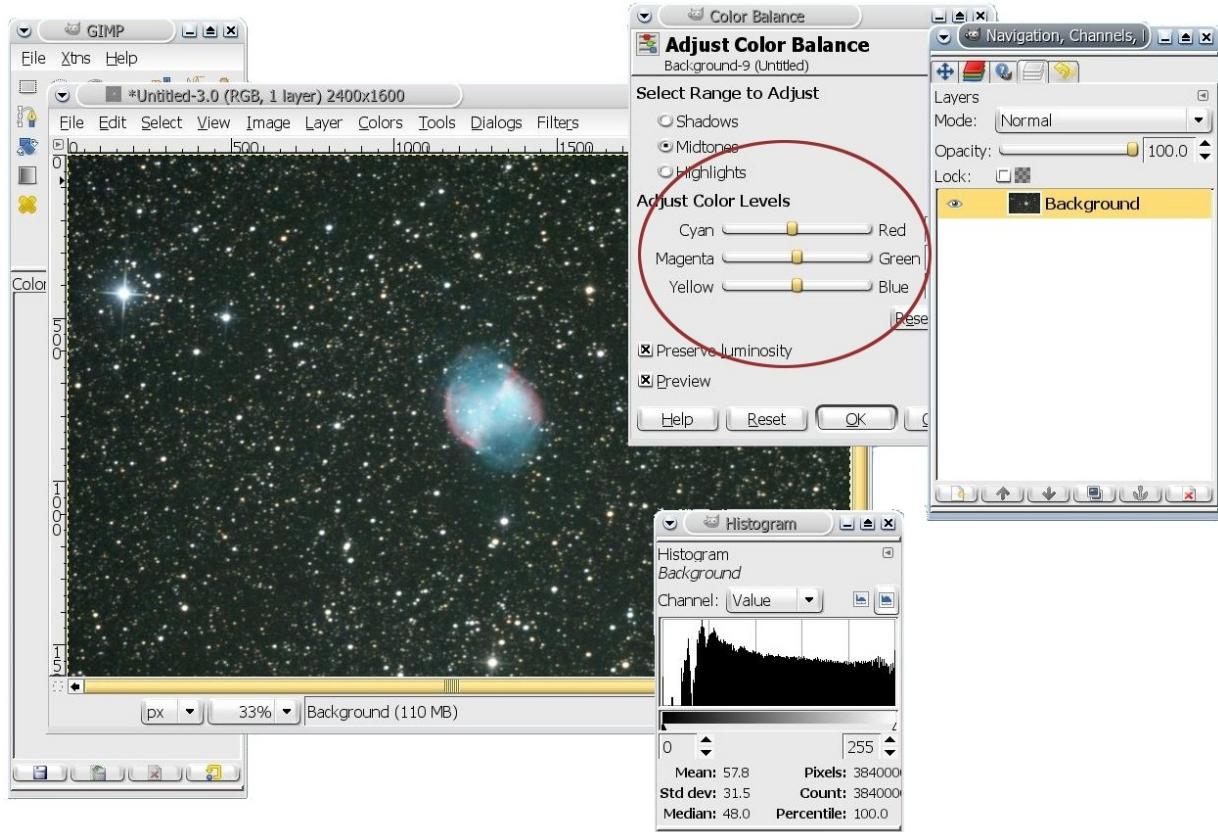


Fig. 145

Now that the balance is roughly set it's time to punch up the colour, to make it 'pop' as it were. To do this I'm going to decompose the image into channels, but not into the RGB channels that we're used to talking about. I'll be using something called LAB which is in the drop-down box under **Colors->Components->Decompose**.

Decomposing to LAB opens a new image window with three layers named L (Luminosity), A (A channel) and B (B channel).

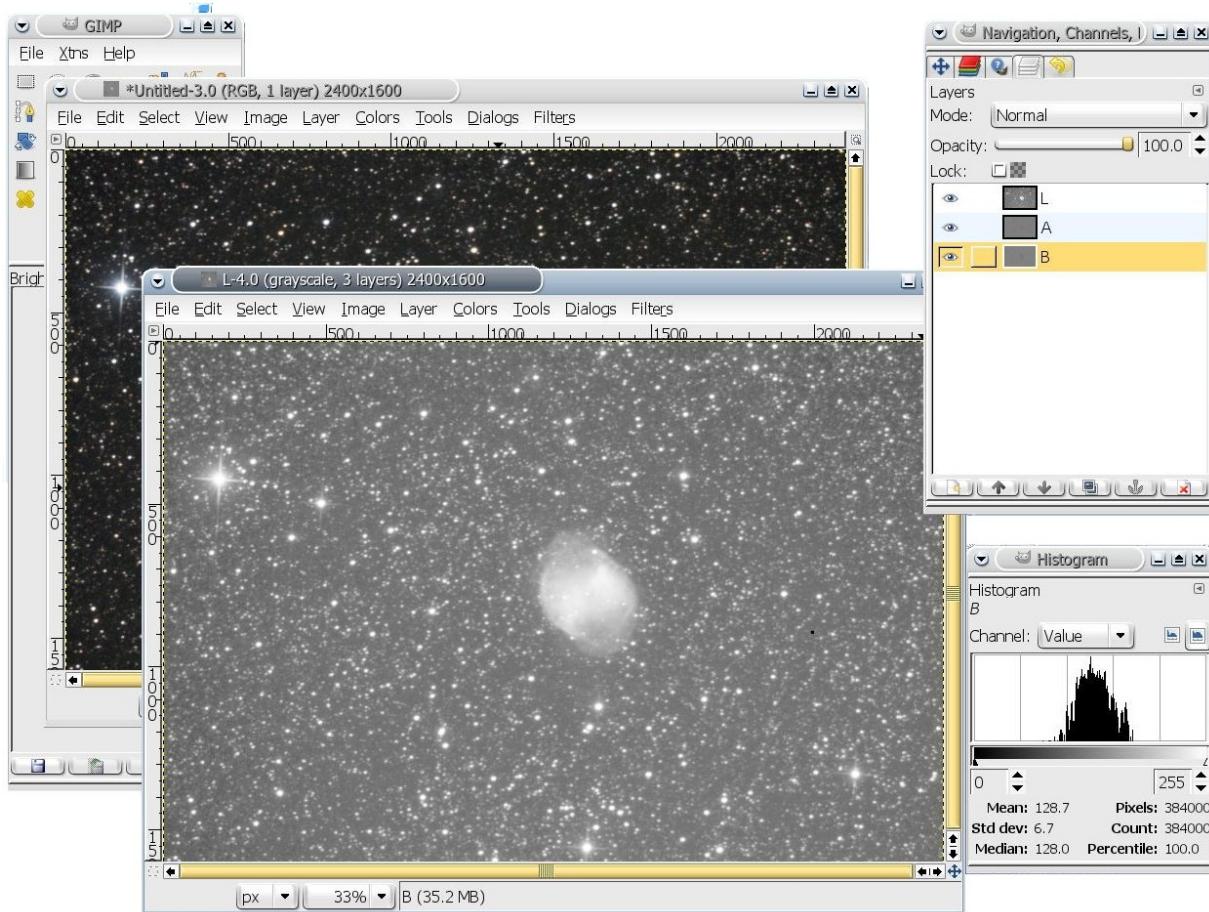


Fig. 146

I Select the A channel then select **Colors->Brightness and Contrast** and pull the contrast up about 25 points. I repeat this with the B channel then I select **Colors->Components->Recompose** in the decomposed image and click on the main image to see the outcome. If the colours need more punch I'll go back to the decomposed image and push the contrast up on the A and B channels again.

When the image has been recomposed the colours are much more vibrant. This generally only works with images of nebulae but I suppose it would also punch up the colour in the HII regions of galaxies.

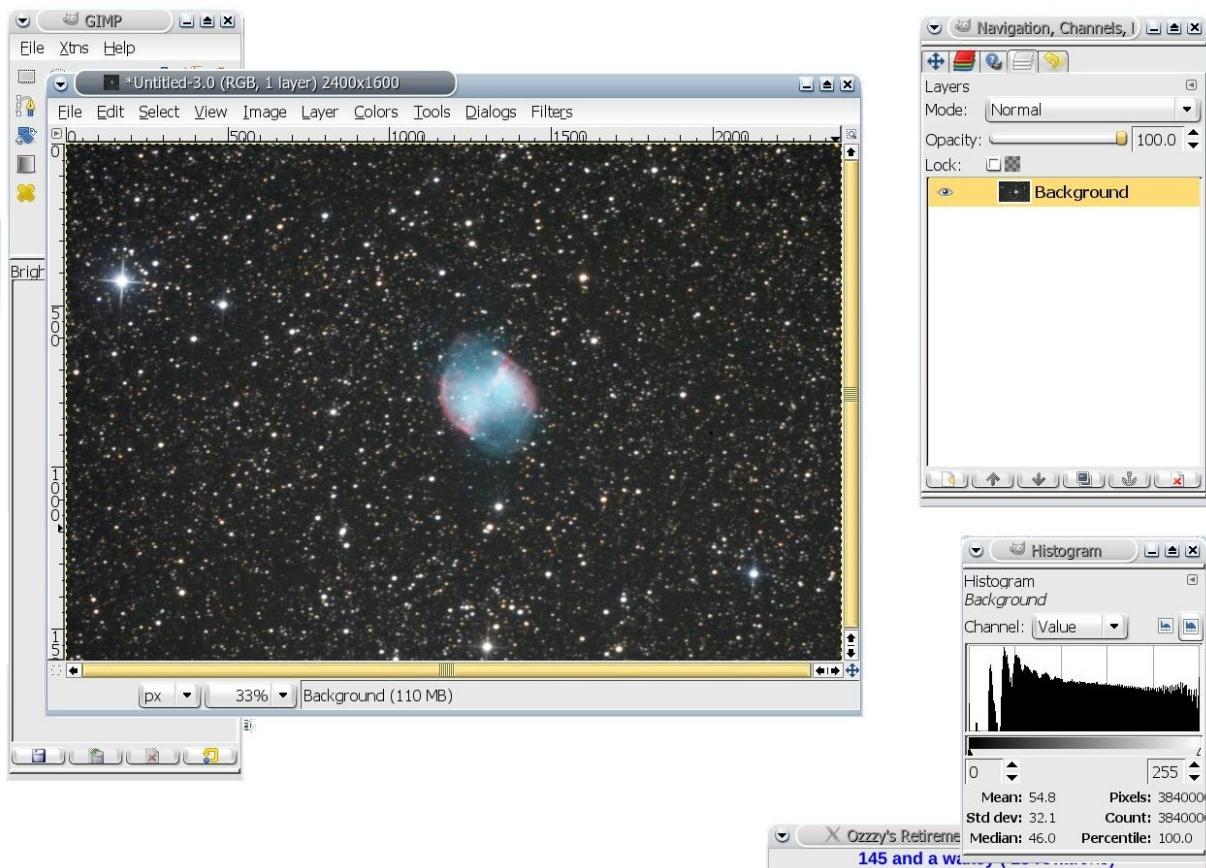


Fig. 147

Now just about all the colour adjustment is done and it's time to think about noise and other enhancements.

I like to handle noise and detail at the same time and have come up with this little procedure that I use quite often.

First I click **Layer->Duplicate Layer** which creates a copy of the main image layer. In that layer I select **Filters->Blur->Gaussian Blur** and set it so that it blurs both directions to 40 pixels. Then I select **Colors->Brightness and Contrast** and drag both Brightness and Contrast back 40 units.

When this is done I select the Background Copy layer in the list and make the layer Mode 'Overlay'. Then I select **Image->Flatten Image**.

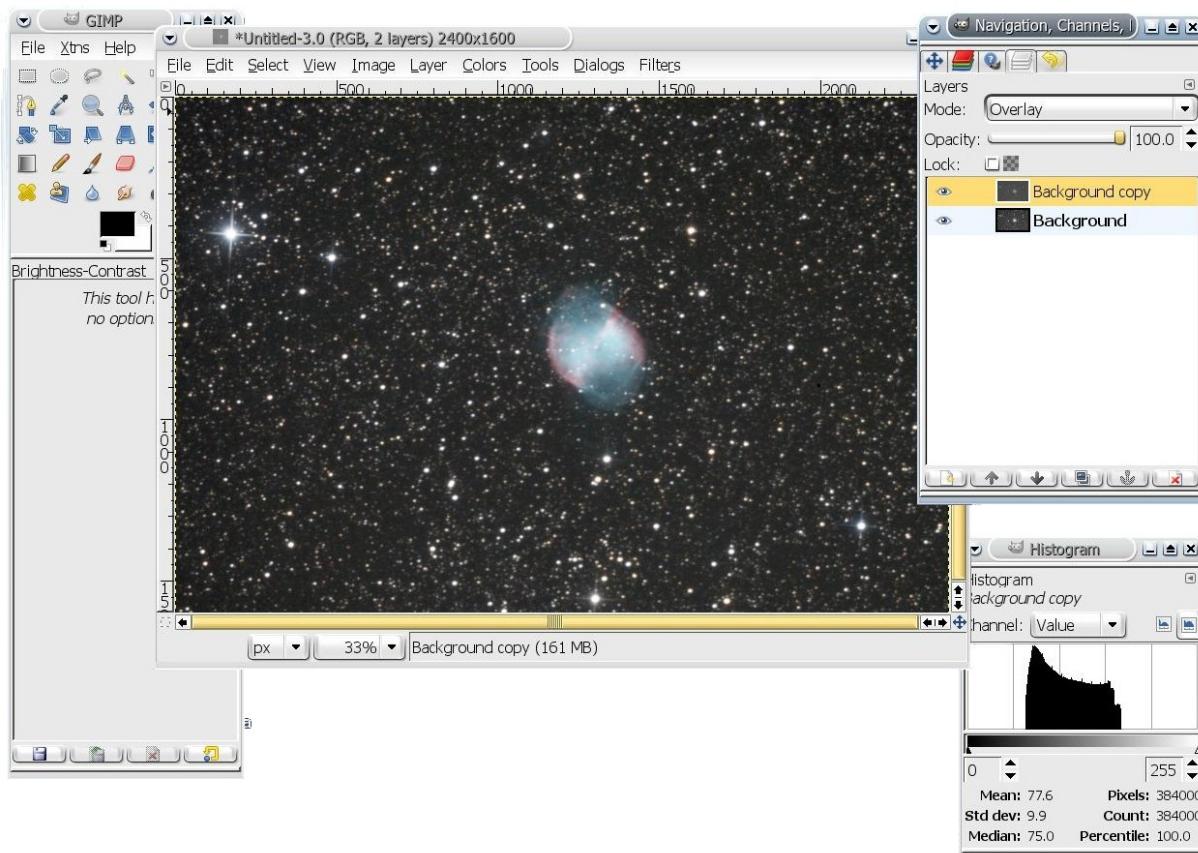


Fig. 148

If there is any noise left over then I use a GIMP plugin called 'Wavelet Denoise' (see the section on GIMP plugins) to get rid of the rest. This does a nice job without many of the artifacts that other anti-noise tools use.

Any further processing will be tinkering with colour, gradient etc.  
This is the outcome of this little processing session:



*Fig. 149*

The GIMP can be downloaded from:

**<http://www.gimp.org>**

## Removing Gradients with the GIMP

There are times when an astro-photo has a noticeable gradient in some direction across the image. This means that the dark sky is lighter on one side than the other (or top to bottom, or on a diagonal). There are fancy tools for getting rid of gradients but the GIMP has a gradient tool that does the trick nicely.

To use this tool select the Gradient Tool from the toolbox (Figure 150) which will display the options for the Gradient tool.

What we want to do with it is to smoothly remove the gradient from the image without losing any detail, or as little detail as possible. To start with set the options as follows:

### Mode

Select Overlay from the drop down list. From the documentation for the GIMP.

*Overlay mode inverts the pixel value of the lower layer, multiplies it by two times the pixel value of the upper layer, adds that to the original pixel value of the lower layer, divides by 255, and then multiplies by the pixel value of the original lower layer and divides by 255 again. It darkens the image, but not as much as with "Multiply" mode.*

That sounds ominous, but it does the trick very nicely for removing a gradient.

### Opacity

Start with the opacity set around 30% and adjust it as needed. We don't want the gradient stomped into the ground but rather gently massaged away.

### Gradient

The gradient type we'll be using is 'FG to Transparent' which starts with the foreground colour and fades it away to nothing as the gradient is added. Make sure that the foreground colour is black.

### Offset

The offset adjusts how far into the gradient add the darkest part extends. Start with about 30% and adjust as needed.

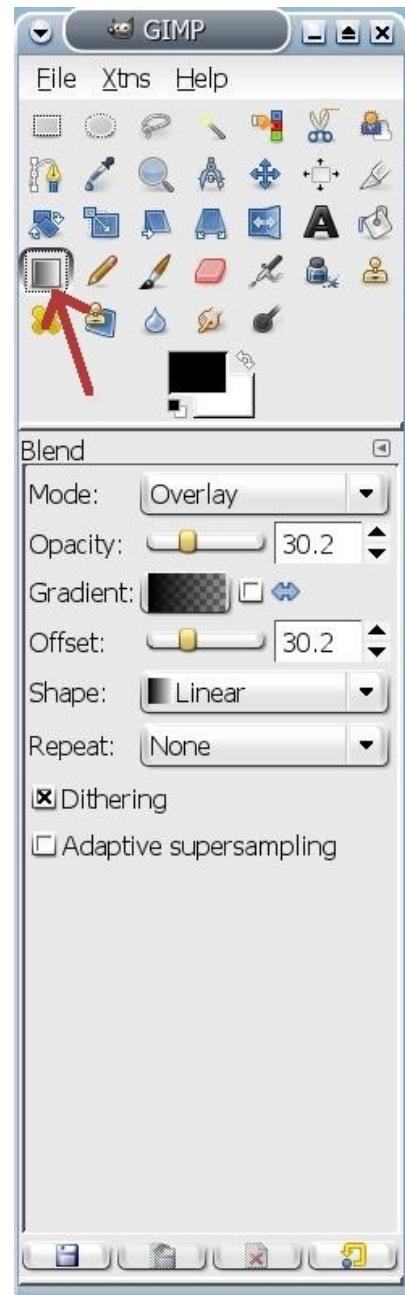
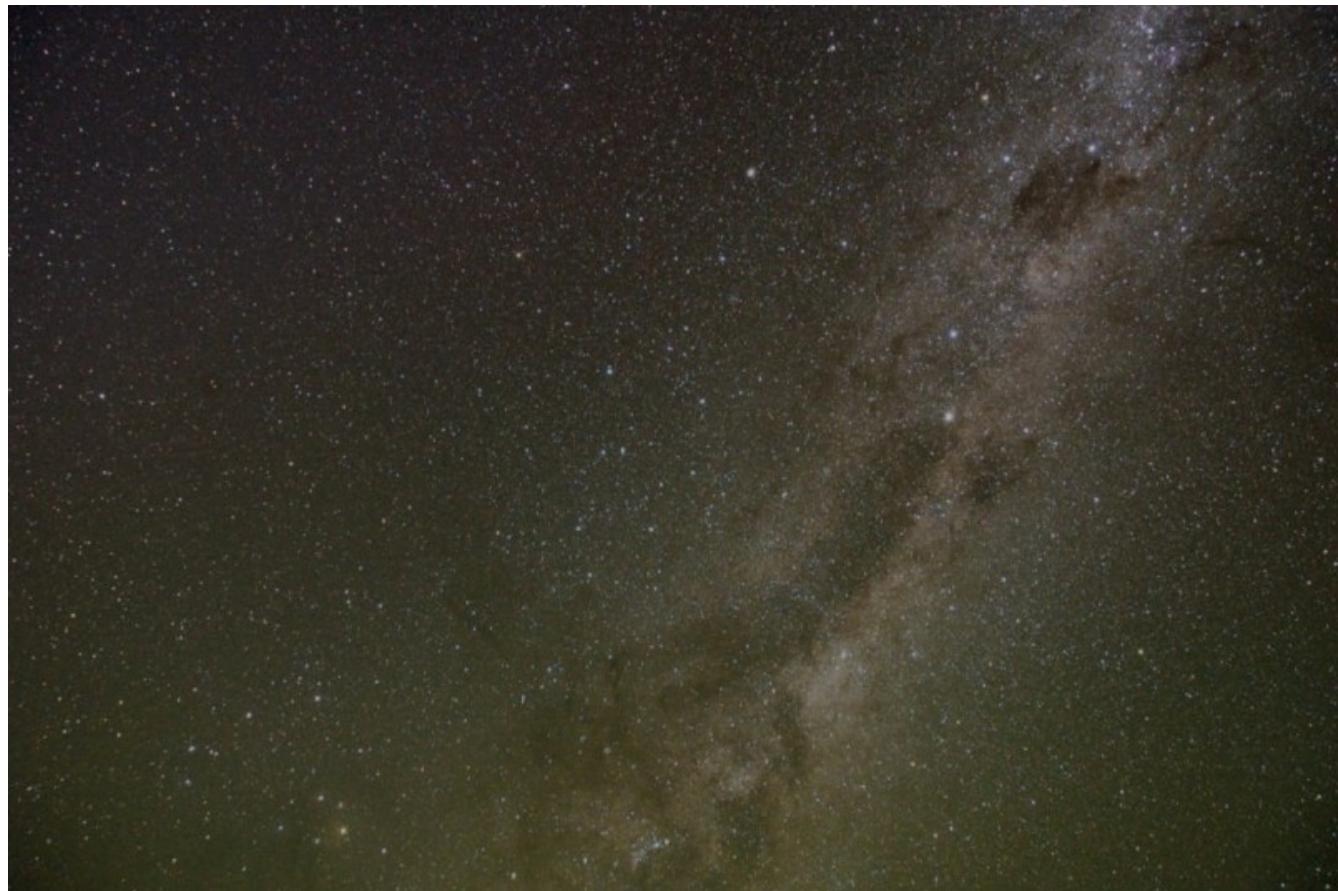


Fig. 150

## Shape

We are removing a gradient that goes in one direction so we'll use Linear.

All of the rest of the options can be left at defaults unless there is a reason to play with them. To activate the gradient, click on the image where you wish to start and then drag the mouse any direction or distance to where you wish to end. When you let go of the mouse button the gradient will be activated and you can see your work. If you wish to adjust then press Ctrl-Z to undo the previous attempt, adjust the parameters and try again.



*The southern Milky Way shot by Dave McCarter in Chile on a tripod-mounted Nikon DSLR.*

## Required Plugins for the GIMP

There are several plugins for the GIMP that really should be kept at hand. I've listed these with their URL in the GIMP Plugin Registry.

### GIMP Wavelet Denoise

<http://registry.gimp.org/node/4235>

The wavelet denoise plugin is a tool to reduce noise in each channel of an image separately. The default colour space to do denoising is YCbCr which has the advantage that chroma noise can be reduced without affecting image details. Denoising in CIELAB ( $L^*a^*b^*$ ) or RGB is available as an option. The user interface allows colour mode and preview channel selection. The denoising threshold can be set for each colour channel independently.

### GIMP Wavelet Sharpen

<http://registry.gimp.org/node/9836>

The wavelet sharpen plugin enhances apparent sharpness of an image by increasing contrast in high frequency space. The amount of unsharpness of the original image can be taken into account by adjusting the sharpening radius. As an option one can choose to sharpen the luminance (YCbCr) channel of the image only.

### GIMP Simple Bilateral Blur

<http://registry.gimp.org/node/24208>

This is a surface blur filter based on a simplified version Porikli's O(1) bilateral filter.

### GIMP Astronomy Plugins

<http://registry.gimp.org/node/2352>

A set of plugins and scripts for astronomical image processing. These are not intended for scientific image processing.

#### **Plugins:**

- Align layers using centre of brightness or 2D (fourier) cross correlation or gauss fit, subpixel-resolution, with de-rotation!
- Merge layers using different mean values, including arithmetic/geometric mean, median, and arithmetic mean of  $x$  sigma around median.

- Create a background gradient (artificial flat field) from a layer by fitting a 2D 4th order polynomial through pivotal points. Cut out large bright nebulae to avoid wrong pivotal point values!
- Star rounding: Round longish stars (due to tracking errors...)
- Create an artificial galaxy. Only elliptical galaxies yet.
- Create artificial stars: Using different star distributions, split into background, object and foreground stars.
- 

### **Scripts:**

- Set mode for all layers
- Set brightness / contrast for all layers
- Normalize all layers
- Subtract dark frame from each layer
- Divide all layers by a flat field
- Draw border with image information

### **GIMP Exposure Blend**

**<http://registry.gimp.org/node/6708>**

This is the 'HDR' plugin. *Exposure-blend* makes quick work of blending 3 bracketed exposures into a detailed, realistic, extended contrast image. It has many features to save the drudgery of assembling contrast blended stacks yourself.



**Do It Yourself Section**  
Simple things that anyone handy can put together

*M33 by Rick Saunders*

## DIY Circuit Boards

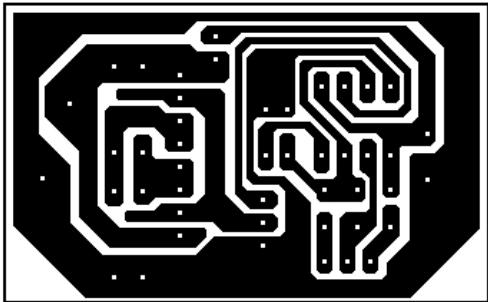


Fig. 151

The basis of the system is that laser printer toner melts when heated and will stick to copper. So a circuit board can be drawn on a computer, scaled to the correct size, printed on the laser printer and then transferred simply to the copper. The copper can then be etched away leaving any protected by the toner behind. This leftover serves as the traces and pads of the circuit board.

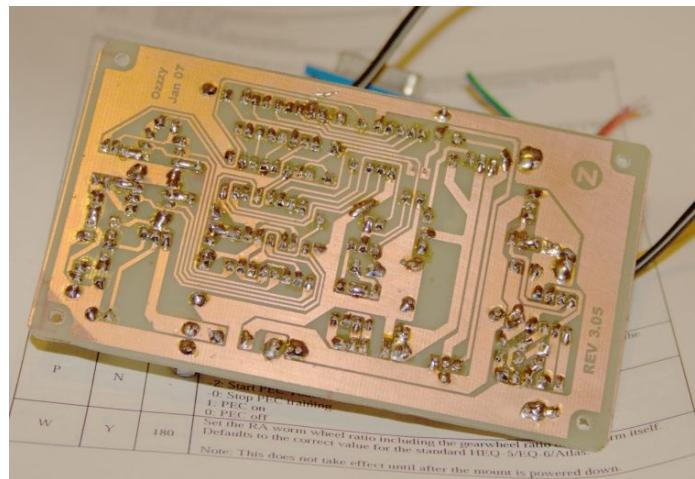
The only specialty item needed is the etchant. Ferric chloride is carried by most shops in liquid form and some may have ammonium sulphate in powder. The powder is easier to keep and doesn't stain things but the solution created by it must be kept quite warm for the best results. This can be had from many sources on-line or, from most electronics supply stores. Other than the etchant all that is needed are:

- 1) A piece of copper-clad. This is fibreglass or plastic with a thin sheet of copper bonded to it.
- 2) An old clothes iron. Steam is not needed and is a detriment so make sure it can be turned off.
- 3) Some glossy photo paper or glossy (white) magazine pages.
- 4) An old tooth brush.
- 5) An old tub or shallow container.
- 6) A Dremel tool with .8 mm and 1 mm drill bits.
- 7) Some acetone.
- 8) A Scotch-brite pad or fine steel wool.

The steps are:

- 1) Create the design in your favourite drawing package or circuit design software. It has to be laid out reversed left-to-right (Figure 151). I prefer the GIMP but just about any will work.
- 2) Print the design onto glossy photo-paper or glossy magazine paper. I always check my design by printing it on regular paper first and checking hole spacing etc.
- 3) Clean a piece of copper-clad circuit board using Scotch-bright pads or steel wool. Use alcohol or acetone to tidy it up after scrubbing.
- 4) Lay the paper toner-side down on the copper-clad board.
- 5) Using an old clothes iron press the printout at high temperature for a minute or so. The heat of the iron will melt the toner which will then stick to the copper when cooled.

- 6) When finished ironing douse the board in cold water.
- 7) Let it soak a bit and then peel the paper away. The toner will stay behind.
- 8) Use a tooth-brush to clean all traces of the paper off of the copper-clad.
- 9) Immerse the copper-clad in an etchant. The container holding the etchant should be in a warm-water bath. This will speed up the process. Agitate it periodically.
- 10) After all of the unwanted copper is gone remove the toner using acetone.
- 11) Drill any holes needed in the board.



The board is now ready to be populated by parts. When all the soldering is over use nail polish (or purchase conformal lacquer spray) to seal the copper away from the elements. The board is now ready to be used.

Figure 152 shows a board that I built that provides focus, anti-dew heat, shutter, auto-guiding and other functions to my Rajiva-modified HEQ5.

There are several free PCB layout tools available with the most popular being Eagle from CadSoft.

## An Efficient DIY Anti-dew Heat Controller

If one is handy with a soldering iron building an effective heater controller is simple. Dave McCarter, president of the London Centre of the RASC has designed a very efficient little circuit that can handle a lot of current.

The circuit is based on a 555 timer and uses a field-effect transistor (FET) to switch the loads on and off. The circuit allows a range in duty-cycle of 5% to 95% and is adjustable using a simple potentiometer.

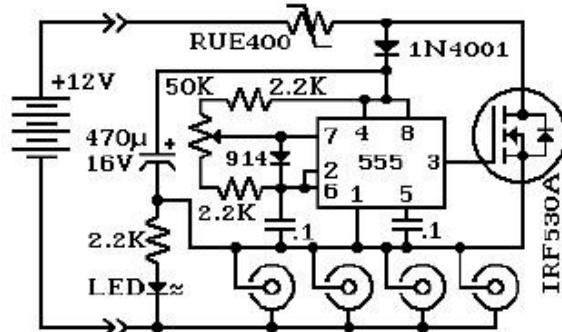


Fig. 153

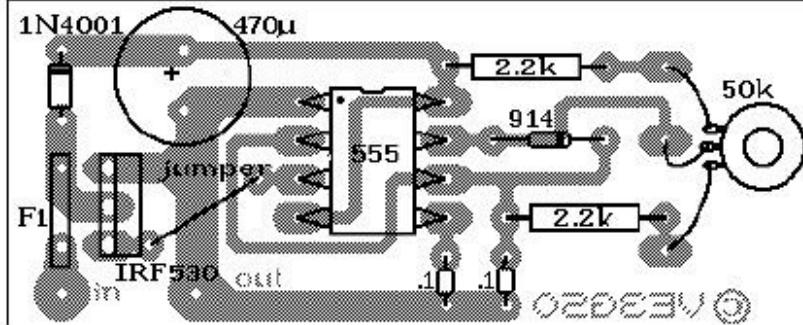


Fig. 154

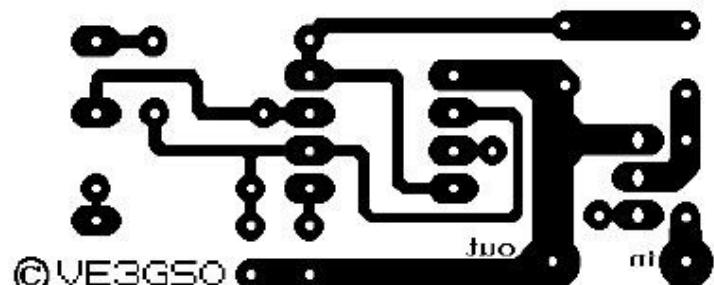


Fig. 155

Above are the schematic, part layout and copper layout for those that wish to make a circuit board. I built my first one on perf-board but using the toner-transfer system for home made boards is so simple that I make boards for everything I build now.

For more information see Dave's article at:

<http://www.astro.uwo.ca/~rasc/HEATER.pdf>



*This guided image of M13 was taken by the author using an unmodified Canon XT and a Stellarvue 102ED refractor.*

## DIY Anti-dew Heat Strip

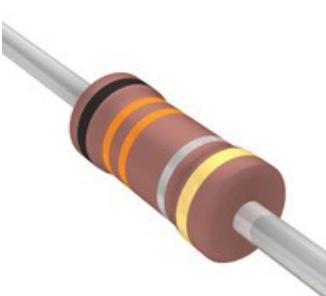
An anti-dew strip is just a resistive load. To build one is quite simple.

### Bill of materials:

- bag of suitable resistors
- some two-lead 20 gauge wire
- a male RCA connector
- some solder
- soldering iron
- a metal coat hanger
- 1/4" heat-shrink tubing
- roll of duct tape

Start by determining how many resistors are required. Measure the inside diameter of the front cell of the optical tube. This heat strip will fit into the cell in front of either the objective or corrector plate. A 1 ohm, 1 watt resistor is about 10 mm long in the body so divide the circumference by 20 mm (two times the body length) to get roughly the number of resistors.

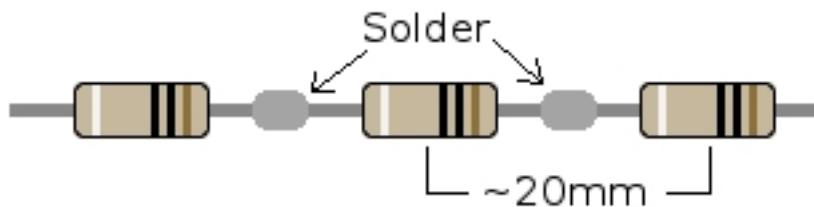
Most medium-sized telescopes can work with 15 W of heat at maximum. Larger telescopes may need 20 W and small refractors less. Let's use the 15 W value for maximum power and 30 resistors in the strip. Dividing 15 by 30 tells us that each resistor needs to radiate  $\frac{1}{2}$  watt of power. Two watt resistors here would be a bit of overkill so select 1watt parts.



We have 15 W at maximum and are spreading it out among 30 resistors. For 15 W at 12 V (nominal) the total resistance of the strip should be  $(12 * 12) / 15$  or about 10 ohms. Ten ohms spread out across 30 resistors in series tells us that we need .33 ohms per resistor. Digikey ([www.digikey.ca](http://www.digikey.ca)) has .33 ohm/1 W resistors in bags of 10 for about 40 cents each (Figure 156). The part number is 0.33WCT-ND

Fig. 156

As I mentioned, the resistors will be soldered together in series, that is, one after the other in a long line (Figure 157). Keep them about 20 mm centre to centre and just keep stringing them until there are more than enough. Then wrap them around the inside of the corrector or objective cell and see how many need to be snipped off and remove these.



*Fig. 157*

The resistor string has to be pulled through the heat-shrink so take some waste wire and solder it to one end of the string of resistors, fish it through the heat-shrink then pull the resistors almost all the way through. Unsolder the waste wire and solder one lead of the two-lead wire onto that end of the resistor string. Pull it through enough to be able solder the other lead onto the far end. Centre and trim the heat-shrink and shrink it into place (I use a lighter or a burner on the gas range). This is your heat strip and should fit nicely in the cell.

Now cut a piece of metal coat hanger to the same length as the finished string of resistors plus 50mm. Cover it with heat-shrink and shrink the tubing on. Bend it into a circle and turn up the two ends 90 degrees and fit it to the cell so that the turned up ends are like handles that can be squeezed together to insert/remove the circle.



*Fig. 158*

Finally, fit the string of resistors to the covered coat hanger and tape them on with ripped bits of duct tape (Figure 158). Solder the male RCA connector onto the end and the heat strip is done.

This will last a long time if it is left in place but this will mean cutting a notch in the dust cover. If used with a dew shield no imaging sessions will ever be ended by a bit of moisture.

## DIY DSLR Power Supply

In the field there is nothing more aggravating than having camera batteries die. This being the case I run my Canon cameras from the 12 V sources that I have at hand. I could have done this using a small DC-AC inverter but that would have been overkill. So I built a 12 V-8 V adaptor for my camera.

The heart of the circuit is an LM317 adjustable output voltage regulator. These are wonderful little chips that can source 1.5 amperes of current while providing a stable voltage source. For the Canon cameras the voltage needed is around 8V so the circuit shown is tuned to that output.

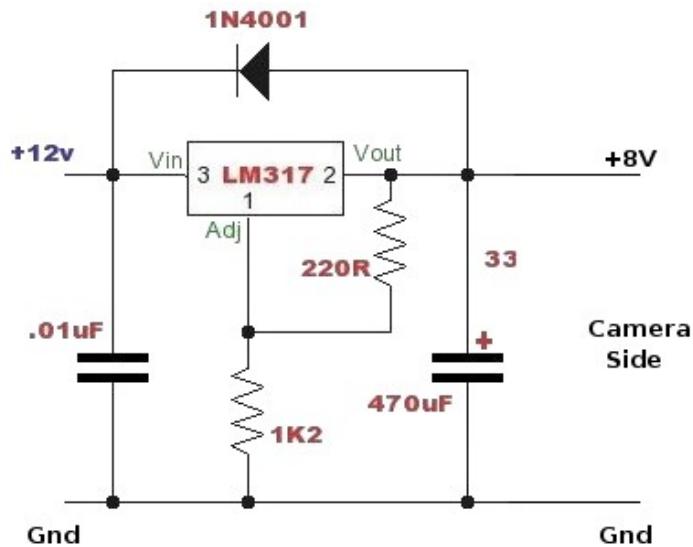


Fig. 159

For any other voltage source the 1200 ohm (1K2) resistor has to be changed out with another that meets the following equation.

$$V_{OUT} = 1.25V \left( 1 + \frac{R_2}{R_1} \right) + I_{ADJ}(R_2)$$

The last value value can be discounted as  $I_{ADJ}$  is very small.

A circuit this small is easily built using perf-board or the parts could just be air-wired together. Some form of heat sink should be used on an LM317. Many people get by without one but a twenty cent part is always good for peace of mind.

Here is a table of resistor values and voltages.

R2 Resistor	Output voltage
680 ohms	5.11 volts
820 ohms	5.91 volts
1000 ohms	6.93 volts
1200 ohms	8.07 volts
1500 ohms	9.77 volts

When the circuit is finished and tested there has to be some way of getting the power into the camera. I suggest purchasing an AC adaptor made for the camera and modifying the cable by adding a 3.5 mm male and female phone plug in-line. Put the male plug on the camera side. If the adaptor has a 3.5 mm female to provide power then the AC adaptor is still usable.

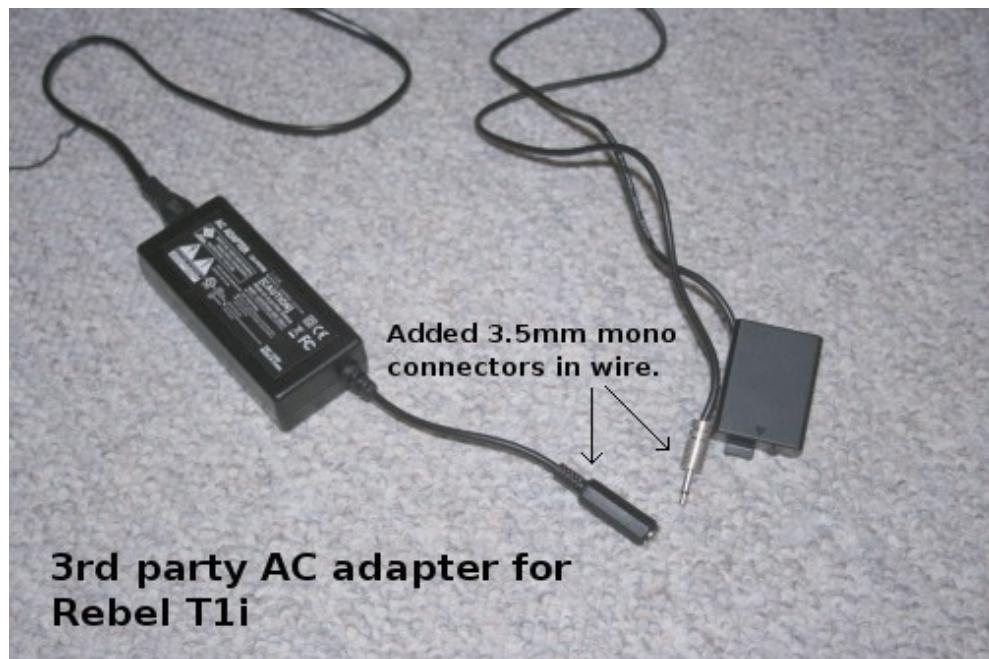


Fig. 160

**Remember that phone plugs short when inserting or removing so plug them in before any power is turned on.**

## DIY USB Hub Power Supply

As the USB ports from a laptop or computer can only source 500 mA of current there are times when the hub needs to be plugged into a wall-wart or other power source. If there are mains near the telescope then a wall-wart is fine. If not then using an inverter for something like a USB hub is overkill.

The best way to power the hub is to use the 12 V that I have on hand.

For this project I used an LM7805 three-terminal positive voltage regulator (Figure 161). These are very handy chips that have on-board short-circuit, over-temp and over-current protection. They come in various output voltages and can handle a 1 ampere load. With large loads they can develop a lot of heat.

### About Heat

The 7800 series chips on their own get hot... sometimes very hot. They heat up around 65 C° for every watt of current that the parts attached to them draw according to the following equation:



Fig. 161

$$\text{Heat generated over ambient (Deg C)} = (\text{Input voltage} - \text{Output voltage}) * \text{current} * T_c$$

( $T_c$  is the thermal resistance of the chip to ambient... 65 C/W with no heat-sink)

This means that if the input voltage is 13.6 V and your output voltage is 5 V then there is a voltage drop of 8.6 V. If the load is 1 A then the chip will heat up to about 550 C° (it won't really, it would have shut itself down when the core got to about 150 C°).

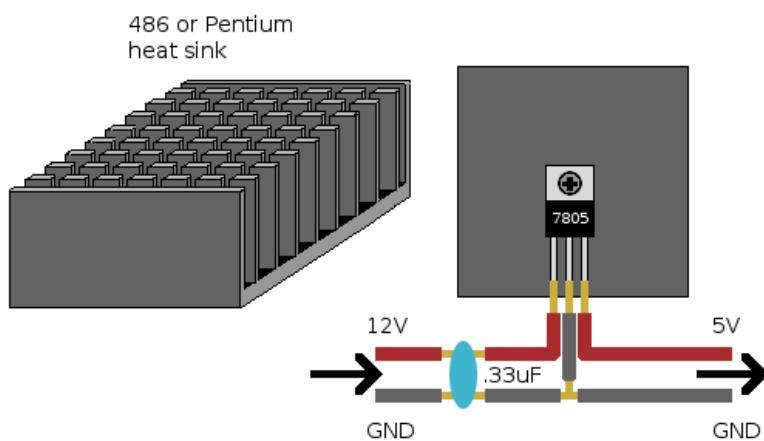


Fig. 162

There has to be some place for the heat to go: a heat-sink. For a 5 V regulator with a 13.6 V source the part reaches too hot somewhere about 200 mA, for an 8V regulator about 300 mA (I have used a bare 7808 to power my Canon T1i): both of these with no heat-sink. This is the 65 C°/W 'thermal resistance to ambient' value of the part. If we add a heat-sink then this value changes and the thermal resistance becomes

that of the heat-sink. So a 10 C°/W heat sink will allow our 5 V part to handle a load of about 1.75 A (higher than it's rated for) In this case, the heat-sink will be very hot but the regulator won't burn up.

For this converter I used a very large heat-sink from a 486 or Pentium (I can't remember) computer that, if I remember correctly, was rated at about 3 C°/W. At full load it should only get to about 25 C° above ambient.

Firstly a hole was drilled and tapped into the back of the heat-sink and the 7805 regulator was screwed tightly onto it. Thermal grease should be used between the 7805 and the heat-sink if available, it helps. Then the positive lead from the source was soldered to the regulator's input leg and the positive lead to the powered device (USB hub) was soldered to the output leg. The input and output ground leads were soldered together with the regulator's ground leg. A .33 uF capacitor is soldered in place from the input positive to ground.

Once this was done it was put into an old project box I had lying around with a suitable cutout made in the box for the heat sink to be able to 'see' the outside air. That's about it. It functions perfectly and, as I mentioned at the top, is very simple.

With a single 7800 series regulator the current limit is 1 ampere. With a 4-port hub it would be nice to provide 500 mA to each port with enough headroom for the port itself. The elegant way to do this would be to use a SimpleSwitcher but there is an inelegant way that is cheap and easy: parallel 7800 regulators. To provide 2.5 A I suggest 4 regulators in parallel. To keep the load balanced a .47 ohm, 1 watt, 1% resistor on each output would work. A .33 uF filter cap on the input and a .01 uF cap (optional) on each output rounds things out. The black common lead in Figure 164 is ground.



Fig. 163

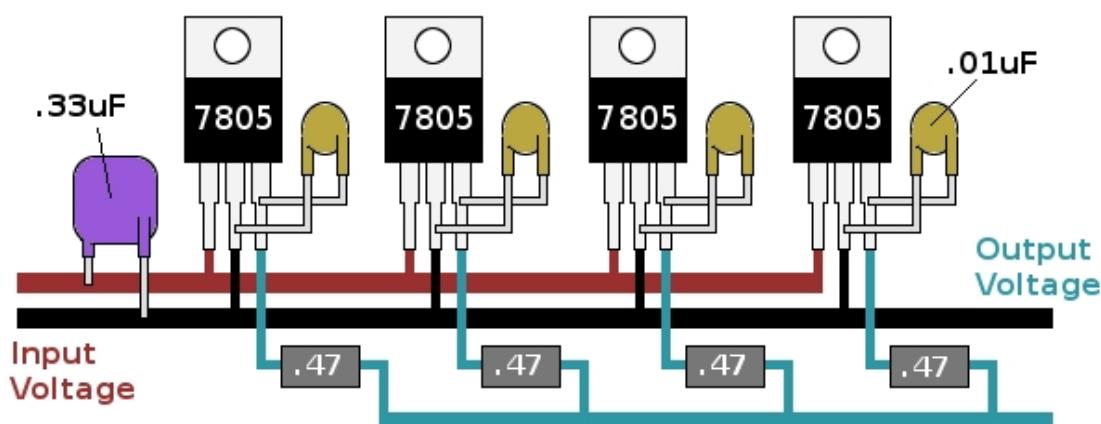


Fig. 164

## Adding a Motor to a Focuser

Being able to control a focuser remotely is quite advantageous. As most imagers work from a computer not having to go back and forth from the console to focus an image saves a lot of time and aggravation.

Building one is not very difficult if access to either a wood or machine shop is available.



Fig. 165

a wooden spool would have sufficed.

On the focuser end the fine-focus knob was replaced by a knob/pulley again machined from brass. The knob that came on the focuser could have had a notch cut in it but brass is so sexy.

A piece of aluminum angle was used for the motor bracket. Suitable holes positioned and drilled on one side allowed the motor to fit in nicely. Slots milled on the other mated with holes in the dovetail to allow the bracket to be adjusted. The whole thing was sculpted on the band-saw and sanded down to be pretty.

Power to the motor comes in via an RCA plug on a piece of L shaped plastic that is screwed to the dovetail. JMI's Moto-Focus controller runs the motor nicely. Connecting the motor to the focuser is a 1/8" rubber O-ring. A belt would be better but geometry wasn't on my side so the ring worked out best for me.

Adding a powered focuser to my AstroTech 8" Newtonian was made simpler by the availability of the finder bracket; the finder having been relegated to other chores. All that was needed was a dovetail that would fit into the bracket and some method of attaching a DC motor to the dovetail. Both of these were taken care of in a friend's machine shop. My parts are aluminum but wood would do just as well.

I had on hand a motor and gearbox that were discarded from the upgrading of my HEQ5 mount and these were pressed into service. A pulley was machined from brass to fit the motor, but having a standard 6 mm output shaft, a pulley could be purchased that would fit. Again,

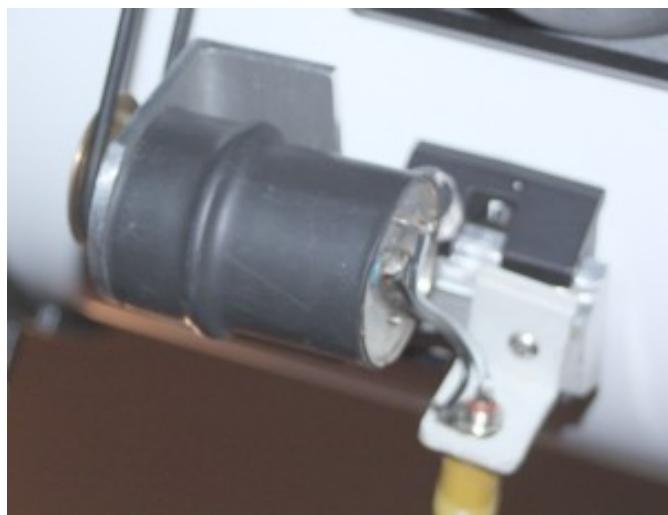


Fig. 166

## DIY Focus Motor Controller

Powered focusers are very nice to use. Being able to focus a telescope with no 'jitters' or 'jumps' in the image while looking through an eyepiece or monitoring a camera makes achieving focus easy. Building one is fairly simple for anyone handy with a soldering iron and the costs are about \$35.

The board I've designed works around a 555 timer circuit to provide variable speed. The timer turns on and off a power FET which provides current to a DC motor. A 50K potentiometer allows speed adjustment and two DPDT on/on push-button switches provide for direction control *and* turn on and off the circuitry. This makes for a very efficient controller which should run for many months on a single 9 V battery.

The schematic is shown in Figure 168.



Fig. 167

### VARIABLE FOCUS CONTROLLER

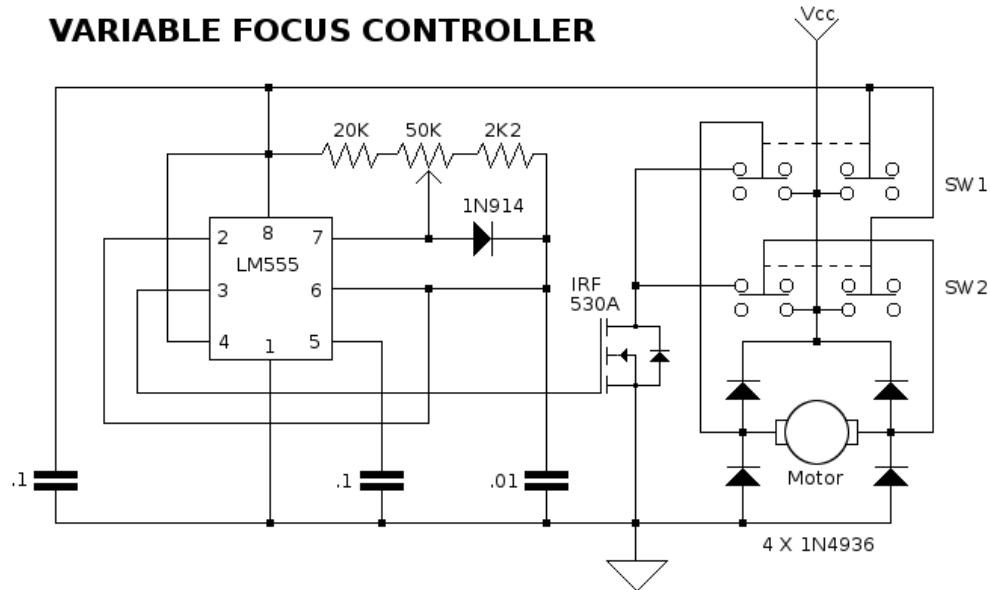


Fig. 168

There is no on/off switch in this circuit as the push-button switches each act to provide power to the timer circuit. There is no power use at all until a direction button is pressed. The switch wiring is shown in Figure 169.

Each switch utilizes 5 of its 6 terminals. The motor side of each switch is labeled E, C and D for 'Enable', 'Common' and 'Default'. These are wired to the corresponding pads in the layout in Figure 170. The Common terminals connect to the motor terminal on Figure 170 (labeled MTR). The E terminal is connected when a button is pressed and the D terminal is connected when a button is not pressed.

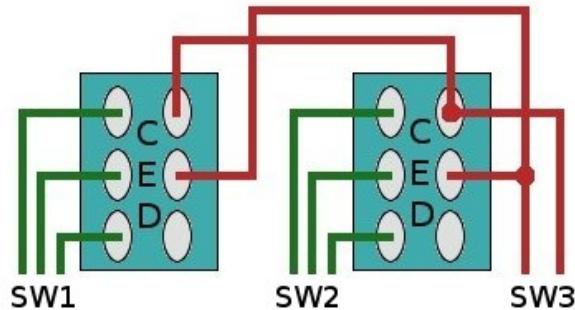


Fig. 169

SW 3 is the other side of each switch and both switches are connected together in parallel and serve to provide power to the timer circuit. The wires going to the SW3 pads in the layout are not polarity-sensitive.

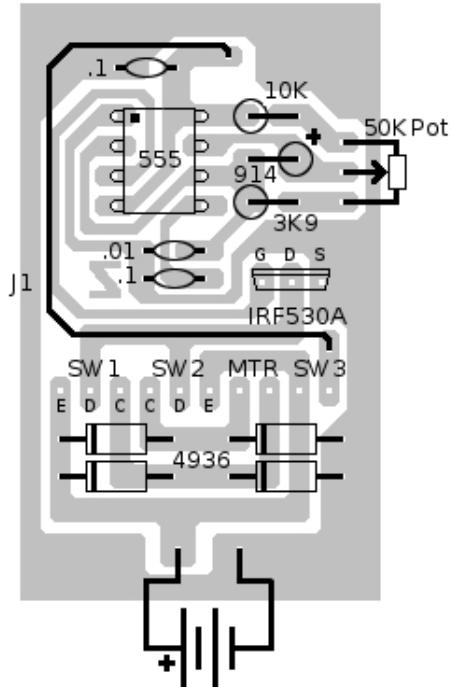


Fig. 170

This unit can provide smoothly variable motor speeds from around 30% to around 95%. Depending on the motor selected this can give extremely slow, and therefore accurate focusing. The circuit is designed to dynamically brake the motor when either button is released which also adds to the accuracy. A motor can be 'pulsed' by quick button presses to move a focuser in extremely small amounts.

The circuit here costs around \$35-40 to build. Most of the parts are common but the switches are not. The DigiKey part number for the switches is 360-2152-ND. All of the other parts can be ordered at the same time.

## Some Nomenclature

Imagers bandy about a lot of terms when it comes to taking and processing images. Things like dark frames, stacking, histogram stretching, etc. will pop up all over the place so I've put a small list of them together.

### **ADU**

An ADU is an Analog/Digital Unit. This is the unit stated to measure the value of a pixel in a CCD image. If the gain of the camera is known then the number of electrons and therefore photons (using the quantum efficiency value) that were collected by the sensor.

### **Amplifier glow**

Known as 'amp glow' this is the heat given off by the electronics in the camera showing up on the image due to heating of the sensor. In Canon Rebels amp glow usually shows up at the bottom right of a frame.

### **Auto-guider**

An auto-guider is a device that uses a digital camera and electronics to move a telescope mount to keep a star centred

### **Bias Frames**

A bias frame (may also be known as 'offset') is an image taken with no actual exposure time. These images are used to adjust the light frames (the actual pictures) to mitigate the noise inherent in the chip itself. If a camera won't take a 0-length image (shot with the shutter closed) then a 'pseudo bias' can be taken by leaving the lens cap on, setting the camera for its fastest shutter speed, standing in a a dark closet and pressing the shutter. Take a few of them. Not to be confused with a dark frame which uses an exposure of the same length as the light (picture) frames.

### **Bit Depth**

A CCD camera's analog signal has to be converted to ditigal values in order for a computer to work with them. This is done by an Analog-Digital converter. The bit depth determines the number of values that can be assigned to a pixel: 256 for 8-bit and 65536 for 16-bit.

### **Collimation**

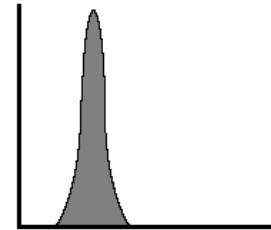
Collimation is the alignment of all of the optical components of a telescope.

## **Dark frames**

These are images taken before, after or during your capture of light frames and are taken with the dust cover on the scope so no light gets in. These are used to adjust the light frames to correct for things like amplifier glow, hot pixels and gradients. They should be taken at the same temperature that the light frames were taken at and have exactly the same exposure settings (ISO, length etc.)

## **Flat frames**

Flat frames are images taken with a constant, 'flat' light source such as that from a light box or the dusk sky. They show up things like dust motes on the sensor, vignetting or uneven illumination in the optical system. Exposed them to about 1/3 histogram as in Figure 171.



*Fig. 171*

## **Full Well Capacity**

This is the number of electrons that a pixel can hold before saturating and possibly causing blooming

## **FWHM**

Full width at half maximum. The width of a star at half-maximum-intensity.

## **Gain**

When a CCD is read the pixel charge may be in micro-volts and an amplifier is needed to bring the signal into the range where it is usable. The amount that the signal is increased is the gain. An amplifier not only reads the signal, but reads any noise inherent in the chip which has to be accounted for.

## **Gradient**

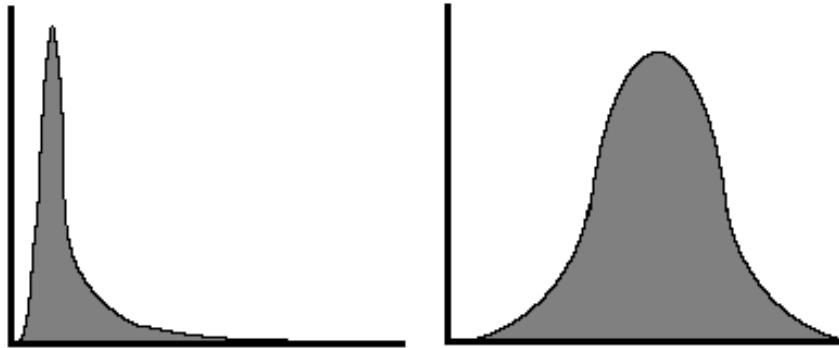
An image showing a gradient has dark sky at one edge lighter than the dark sky at another edge. This is not wanted. Some gradients such as those caused by the optical system can be handled by flat frames, others need a bit of ingenuity.

## **Histogram**

A histogram is a graph of how many pixels of each intensity level occur in an image. They are X/Y graphs and show pixel intensity along the X axis and number of pixels on the Y axis. An unstretched histogram may look like a flat line with a large spike at the far left side.

## **Histogram stretching**

Turning the histogram with a 'flat line with a bump' into a wide-based mountain. Most software allows this to be done linearly (levels) or non-linearly (curves).



*Fig. 172*

### **Hot pixels**

These are pixels that have 'turned on' on your sensor for whatever reason. They show up in the image as static red, green or blue 'dots' that are fairly bright. Dark frames usually get rid of them but sometimes one has to go through a final image removing them with the clone stamp tool.

### **Light frames**

These are the actual pictures. The shutter is open, the telescope is tracking and the sensor is being bathed in ancient photons.

### **Quantum efficiency (QE)**

The percentage of [photons](#) hitting the photo reactive surface that will produce an electron-hole pair (the electron in our bucket).

### **Skyglow limit**

Every image will show *some* skyglow which is just the brightness of the background (or foreground if it's due to light pollution). The skyglow limit is the length of exposure where the skyglow swamps any actual data.

### **Sensitivity**

Modern sensors are usable to very low light levels and therefore are considered highly sensitive. Many can operate down to near zero lux (lumens/sq. metre).

### **Stacking**

Stacking involves taking many short exposures and adding them together to make one long duration exposure. Good software will register (align) all of the images while it stacks them.

## Links

### Mounts

AstroPhysics	<a href="http://www.astro-physics.com">http://www.astro-physics.com</a>
Celestron	<a href="http://www.celestron.com">http://www.celestron.com</a>
Losmandy	<a href="http://www.losmandy.com">http://www.losmandy.com</a>
Meade	<a href="http://www.meade.com">http://www.meade.com</a>
Orion	<a href="http://www.telescope.com">http://www.telescope.com</a>
SkyWatcher	<a href="http://www.skywatchertelescope.net">http://www.skywatchertelescope.net</a>
Vixen	<a href="http://www.vixenoptics.com">http://www.vixenoptics.com</a>

### Tripods and Piers

Telescope Perf. Improvements <http://www.tpiastro.com>

### Optics

ASA	<a href="http://www.astrosysteme.at">http://www.astrosysteme.at</a>
Astronomy Technologies	<a href="http://www.astronomytechnologies.com">http://www.astronomytechnologies.com</a>
AstroPhysics	<a href="http://www.astro-physics.com">http://www.astro-physics.com</a>
Borg	<a href="http://www.sciencecenter.net/hutech/borg/">http://www.sciencecenter.net/hutech/borg/</a>
Celestron	<a href="http://www.celestron.com">http://www.celestron.com</a>
GSO	<a href="http://www.gs-telescope.com">http://www.gs-telescope.com</a>
Meade	<a href="http://www.meade.com">http://www.meade.com</a>
Orion	<a href="http://www.telescope.com">http://www.telescope.com</a>
Planewave	<a href="http://www.planewave.com">http://www.planewave.com</a>
Questar	<a href="http://www.questarcorporation.com">http://www.questarcorporation.com</a>
RCOS	<a href="http://www.rcopticalssystems.com">http://www.rcopticalssystems.com</a>
Stellarvue	<a href="http://www.stellarvue.com">http://www.stellarvue.com</a>
TeleVue	<a href="http://www.televue.com">http://www.televue.com</a>
Vixen	<a href="http://www.vixenoptics.com">http://www.vixenoptics.com</a>
William Optics	<a href="http://www.williamoptics.com">http://www.williamoptics.com</a>

### Rings and Dovetails

ADM	<a href="http://admaccessories.com">http://admaccessories.com</a>
Antares	<a href="http://www.antaresoptical.com">http://www.antaresoptical.com</a>
Ken's Rings	<a href="http://www.kendauzat.net">http://www.kendauzat.net</a>
Losmandy	<a href="http://www.losmandy.com">http://www.losmandy.com</a>
Orion	<a href="http://www.telescope.com">http://www.telescope.com</a>
Vixen	<a href="http://www.vixenoptics.com">http://www.vixenoptics.com</a>

## **Electrical Power**

Canadian Tire  
Kendrick  
WalMart Canada

<http://www.canadiantire.com>  
<http://www.kendrickastro.com>  
<http://www.walmart.ca>

## **DSLR Cameras**

Canon  
Hutech  
Nikon  
Olympus  
Pentax

<http://www.canon.ca>  
<http://www.sciencecentre.net/hutech>  
<http://www.nikon.ca>  
<http://www.olympuscanada.com>  
<http://www.pentaxcanada.com>

## **CCD Cameras**

Apogee  
QHY  
SBIG  
StarlightXpress

<http://www.ccd.com>  
<http://www.qhyccd.com>  
<http://www.sbig.com>  
<http://www.starlight-xpress.co.uk>

## **Astro-photography With Camera Lenses**

Astrotrac  
Two Old Guys Astrogear  
Chris L. Peterson

<http://www.astrotrac.com>  
<http://www.togastro.com/>  
<http://www.cloudbait.com>

## **Guiders**

Borg  
Celestron  
KW Telescope  
Orion  
QHY  
SBIG  
Author's site

<http://www.sciencecenter.net/hutech/borg/>  
<http://www.celestron.com>  
<http://www.kwtelescope.com>  
<http://www.telescope.com>  
<http://www.qhyccd.com>  
<http://www.sbig.com>  
[http://www.togastro.com/ozzy/finder\\_guider.html](http://www.togastro.com/ozzy/finder_guider.html)

## **Focusers**

Antares  
JMI  
Moonlight Telescope Acc.  
Orion  
Starlight Instruments  
William Optics  
Robo-Focus  
Author's site

<http://www.antaresoptical.com>  
<http://www.jimsmobile.com>  
<http://www.focuser.com>  
<http://www.telescope.com>  
<http://www.starlightinstruments.com>  
<http://www.williamoptics.com>  
<http://www.robofocus.com>  
[http://www.togastro.com/ozzy/at8in\\_mods.html](http://www.togastro.com/ozzy/at8in_mods.html)

## **Focusing Masks**

Ozzzy's Place  
Bahtinov Grabber  
Lazer Tech

[http://www.togastro.com/ozzzy/bahtinov\\_masks.html](http://www.togastro.com/ozzzy/bahtinov_masks.html)  
<http://www.njnoordhoek.com/?p=325>  
<http://www.lazer-tech.ca/company.html>

## **Automatic or Remote Focusing**

Two Old Guys Astrogear  
Technical Innovations  
Lunático Astronomia

<http://www.togastro.com>  
<http://www.robofocus.com>  
<http://tienda.lunatico.es>

## **Field Flatteners/Reducers/Correctors**

Astronomy Technologies  
AstroPhysics  
Celestron  
Meade  
Orion  
William Optics  
Baader Planetarium  
TeleVue

<http://www.astronomytechnologies.com>  
<http://www.astro-physics.com>  
<http://www.celestron.com>  
<http://www.meade.com>  
<http://www.telescope.com>  
<http://www.williamoptics.com>  
<http://www.baader-planetarium.com>  
<http://www.televue.com>

## **USB Hubs**

Belkin

<http://www.belkin.com/>

## **Dew Control**

Kendrick  
Orion  
Thousand Oaks  
Author's site

<http://www.kendrickastro.com>  
<http://www.telescope.com>  
<http://www.thousandoaksoptica.com>  
[http://www.togastro.com/ozzzy/my\\_dew\\_zapper.html](http://www.togastro.com/ozzzy/my_dew_zapper.html)

## **Filters**

Astrodon  
Astronomik  
Hutech  
Lumicon  
Orion

<http://www.astrodon.com>  
<http://www.astronomik.com>  
<http://www.sciencecentre.net/hutech>  
<http://www.lumicon.com>  
<http://www.telescope.com>

## **Exposure Control**

Two Old Guys Astrogear

<http://www.togastro.com>

## **Flat Frames**

Greg Pyros  
David Haworth

<http://www.gregpyros.com>  
<http://www.stargazing.net/david/>

## **Collimation**

Cat's Eye Collimation	<a href="http://www.catseyecollimation.com">http://www.catseyecollimation.com</a>
Celestron	<a href="http://www.celestron.com">http://www.celestron.com</a>
Hotech	<a href="http://www.hotechusa.com">http://www.hotechusa.com</a>
Howie Glatter	<a href="http://www.collimator.com">http://www.collimator.com</a>
Meade	<a href="http://www.meade.com">http://www.meade.com</a>
Orion	<a href="http://www.telescope.com">http://www.telescope.com</a>
Bob's Knobs	<a href="http://www.bobsknobs.com/">http://www.bobsknobs.com/</a>

## **DIY Circuit Boards**

CadSoft	<a href="http://www.cadsoftusa.com">http://www.cadsoftusa.com</a>
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Hardware Section Page	Jon Gunning
Processing Section Page	Jon Gunning

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LX200	Chip Frappier	<a href="http://sites.google.com/site/whistlestopobs">http://sites.google.com/site/whistlestopobs</a>
German Equatorial Mount	Wikipedia Commons/Marie-Lan Nguyen	

## Tripods and Piers

AP1200 Pier	Astro-Physics	<a href="http://www.astro-physics.com">http://www.astro-physics.com</a>
Accessory Shelf	Starizona	<a href="http://www.starizona.com">http://www.starizona.com</a>
CGE Tripod Brace/Shelf	Telescope Performance Improvements	<a href="http://www.tpiastro.com">http://www.tpiastro.com</a>

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Meade f/3.3 Focal Reducer	Meade Corp.
Coathanger Asterism Area	Ryan Fraser

<http://www.meade.com>

## Mounting Rings and Dovetail Bars

Telescope Rings	Orion Telescopes and Binoculars	<a href="http://www.telescope.com">http://www.telescope.com</a>
Rotating Rings	Parallax Instruments	<a href="http://www.parallaxinstruments.com">http://www.parallaxinstruments.com</a>
Dovetail Bars	Astronomy Technologies	<a href="http://www.astronomytechnologies.com">http://www.astronomytechnologies.com</a>
Heart Nebula	Jon Gunning	

## Electrical Power

Regulated Power Supplies	Kendrick Astro Instruments	<a href="http://www.kendrickastro.com">http://www.kendrickastro.com</a>
Inverter	Canadian Tire Corp.	<a href="http://www.canadiantire.com">http://www.canadiantire.com</a>

## Sensors

Blooming	Wikipedia Commons/Genetichazzard
Multi-panel sensor	Wikipedia Commons/Sloan Digital Sky Survey

## **DSLR Cameras**

Prime Focus Adaptor	Orion Telescopes and Binoculars	<a href="http://www.telescope.com">http://www.telescope.com</a>
Bayer Filter	Wikipedia Commons/Colin M. L. Burnett	
Canon T1i	Canon Canada	<a href="http://www.canon.ca">http://www.canon.ca</a>
Nikon DR-6 finder	Nikon USA	<a href="http://www.nikonusa.com">http://www.nikonusa.com</a>

## **CCD Sensors**

SBIG ST-8300M	Santa Barbara Instruments Group	<a href="http://www.sbig.com">http://www.sbig.com</a>
QHY9 Cameras	QHYCCD	<a href="http://www.qhyccd.com">http://www.qhyccd.com</a>
IC405	Bill Gardner	

## **Astro-photography With Camera Lenses**

Nikon D200	Nikon USA	<a href="http://www.nikonusa.com">http://www.nikonusa.com</a>
Barndoor Tracker	Chris L. Peterson	<a href="http://www.cloudbait.com">http://www.cloudbait.com</a>
Astrotrac	Astrotrack	
Piggy-back Adaptor	Meade Corp.	<a href="http://www.meade.com">http://www.meade.com</a>
Andromeda Galaxy	Dan Williams	

## **Auto-guiders**

Celestron NexGuide	Celestron Corp.	<a href="http://www.celestron.com">http://www.celestron.com</a>
SG-4 Camera	Santa Barbara Instruments Group	<a href="http://www.sbig.com">http://www.sbig.com</a>
ST-4 Star Tracker	Santa Barbara Instruments Group	<a href="http://www.sbig.com">http://www.sbig.com</a>
Crab nebula	Pete Raine	

## **Focusers**

Rack and Pinion	Wikipedia Commons/US Federal Gov't	
JMI MOTO-Focus	Jim's Mobile Inc.	<a href="http://www.jimsmobile.com">http://www.jimsmobile.com</a>

## **Focusing Masks**

Bahtinov Mask	Wikipedia Commons/astrojargon.net	
Carey Mask	Wikipedia Commons/Axelottal	

## **Automatic and Remote Focusing**

FWHM	Wikipedia Commons/Arne Nordmann	
Robo-Focus	Technical Innovations	<a href="http://www.robofocus.com">http://www.robofocus.com</a>
Seletek Armadillo	Lunático Astronomia	<a href="http://tienda.lunatico.es">http://tienda.lunatico.es</a>
JMI PC Focus Control	Jim's Mobile Inc.	<a href="http://www.jimsmobile.com">http://www.jimsmobile.com</a>
TOGA LX Guider/Focuser	Two Old Guys Astrogear	<a href="http://www.togastro.com">http://www.togastro.com</a>

## **Field Flatteners, Focal Reducers and Coma Correctors**

Williams Optic Flattener III	Williams Optic	<a href="http://www.williamsoptic.com">http://www.williamsoptic.com</a>
RCOS Flattener	RC Optical Systems	<a href="http://www.rcopticalsystems.com">http://www.rcopticalsystems.com</a>
Meade f/6.3 Flattener/Reducer	Meade Corp.	<a href="http://www.meade.com">http://www.meade.com</a>
MPCC	Baader Planetarium	<a href="http://www.baader-planetarium.com">http://www.baader-planetarium.com</a>
ParaCorr	TeleVue	<a href="http://www.televue.com">http://www.televue.com</a>

## **Dew Control**

Kendrick's Premier Controller  
Thousand Oaks Controller

Kendrick Astro Instruments  
Thousand Oaks Optical

<http://www.kendrickastro.com>  
<http://www.thousandoaksoptical.com>

## **USB Hubs**

Belkin 4-port Hub  
Omega Centauri

Belkin  
Jon Gunning

<http://www.belkin.com>

## **Filters**

Lumicon Filters  
Astronomik EOS Clip  
Filter Wheel  
Dumbbell Nebula in O-III

Lumicon  
Astronomik  
Apogee Imaging Systems  
Robert J. Vanderbei

<http://www.lumicon.com>  
<http://www.astronomik.com>  
<http://www.ccd.com>

## **Telescope Balance**

SCT Balance Set

AstroEngineering

[www.astro-engineering.com](http://www.astro-engineering.com)

## **Exposure Control**

Canon TC-80  
TOGA Intervalometer

CanonUSA  
Two Old Guys Astrogear

<http://www.canonusa.com>  
<http://www.togastro.com>

## **Collimation**

Star Images  
Cheshire Sight Tube  
Hotech SCA Laser Collimator  
Laser dot image  
Star Images

?  
Orion Telescopes and Binoculars  
Hotech Corp.  
Hotech Corp.  
?

<http://www.telescope.com>  
<http://www.hotechusa.com>  
<http://www.hotechusa.com>

## **Flat Frames**

Light Box  
Pentax and Laptop

Greg Pyros  
David Haworth

<http://www.gregpyros.com>  
<http://www.stargazing.net/david/>

## **Removing Gradients**

Southern Milky Way

David McCarter

## **DIY Anti-Dew Heat Controller**

All illustrations

David McCarter

## **DIY Anti-Dew Heat Strip**

Resistor

DigiKey Corp.

<http://www.digikey.ca>

## **DIY USB Power Supply**

Regulator

DigiKey Corp.

<http://www.digikey.ca>