Remote Observatory Annual Review 2012 (Part I)

1. Overview

It has been a year since my remote observatory in Australia started operation in late 2011. I believe it is a good time to review how the project goes and also to summarise what I have learned during the past year. Overall, I would say the project has been extremely successful and far exceeds what I originally expected. There were obviously all sorts of hiccups along the way. But considering the complexity of operating a remote observatory, it has been much smoother than what I have imagined.

Everyone who has attempted to do deep sky imaging knows that it is no easy task to get a decent image. Although the objects are always there waiting to be imaged and the entire process seems mechanical, many things can go wrong and will go wrong during the process. Solving all these expected and unexpected problems is a major part of the fun for this challenging hobby. Now consider all your equipments are thousands of kilometers away, try to make it all work is a daunting task.

I believe the most important reason for my success is due to the fact that I started the project at the right time. Only until very recently did all the related hardware and software components become mature and readily available to amateurs. Without these building blocks, it is almost impossible to construct a highly automated remote observatory by an amateur. I think we are lucky to be living in this era and be able to greatly extend the imaging possibilities via building our own remote observatories. In this review, I'll try to examine some of the individual components to reveal what I've learned. I hope this can be useful to someone who is interested in building his own remote observatory.

First of all, below are some imaging statistics for the past year:

Total Exposure: 1,613 hours
Total Frames: 9,324
Objects Completed: 98
Objects In Progress: 13
Average Exposure Per Day: 4.36 hours

2. Site location

My remote observatory is located in Coonabarabran, Australia. When choosing a suitable site, there are a number of attributes one needs to consider, some important ones include:

- Latitude - should not be too high or too low. Too high a latitude means you are only limited to objects in either the southern or the northern part of the sky. Too low a latitude means objects near the pole will never be high enough for good imaging. I believe a latitude of around 30 degrees to be around optimal. My site is at 31.28 degrees south.

- Altitude - usually as high as possible, but not always. Obviously the higher you are located, the thinner the atmosphere is above you and you should also be less affected by polluted air. However, surrounding landscape is also important and sometimes even more important than absolute altitude. For instance, the Siding Spring Observatory (locate on the mountain top 12 km away), at ~1000m, is about twice as high as my site. Based on my observations over the past year, my site has significantly more clear skies for imaging because the mountain top is often affected by mist and clouds.

- Darkness - obviously as dark as possible. In practice, you can rarely find sites darker than around 22 mag per square arcsec. My site is typically around 21.5 to 22 on clear moonless nights.

- Percentage clear nights - obviously the higher the better. In my opinion, a good site should have more than 50% clear nights averaged throughout the year. Though I have yet to see a strict definition of this term, my site claims to have 65% clear nights, which is considered quite high. More on this below.

- Seeing - this is very important for high resolution imaging. A good site should have 1 to 2 arcsec seeing on steady nights. This allows high resolution imaging and is vital for long focal length setups. An excellent site may have <1 arcsec seeing at times, but such sites are rare. My site's seeing was around 2.5-3.5 arcsec on typical nights, and may reach ~2 arcsec on good nights. These figures are mediocre and significantly limits my ability to do high resolution imaging. More on this below.

3. Percentage clear nights

Based on the average exposure per day and other parameters, we can estimate the percentage clear nights for a site.

Length of the night for a particular location varies throughout the year, longer in winter and shorter in summer. Averaged through the year, it should be 12 hours for any location. However, the sky is typically not dark enough for imaging unless the sun is at least 1 hour below horizon. Therefore, we only have approximately 10 hours of imaging time for each night on average. Due to equipment problems, I estimate that about 10% of the time was lost. While imaging, there are significant overheads including: image download, periodic autofocus, slewing between targets, autoguide setup, job scheduling etc. For my case, this amounts to ~30%. Therefore, the net available exposure time becomes ~6.3 hours (= 10 * 0.9 * 0.7) per night.

Given my average exposure per day figure of 4.36 hours, this implies my site's percentage clear night should be ~69% (4.36 / 6.3). This is very close to the claimed figure of 65% for the site. But of course, this figure can vary significantly from year to year.

Average available imaging time per day: 10 hours
Equipment failure overhead: 10%
Imaging overheads (slew, autofocus, guiding, scheduling etc): 30%
Net available imaging time per day: 6.3 hours
Average exposure per day: 4.36 hours
Clear night percentage: 69%

4. Seeing

As mentioned above, my site's typical seeing was 2.5-3.5 arcsec and at best ~2 arcsec on a good night. This is not good for high resolution imaging and precludes the employment of long focal length setups. My current scope is a 180mm (7") APO refractor at 1287mm focal length (f/7.2). Coupled with a 8300 sensor camera, which has 5.4um pixels, it gives an image scale of 0.87 arcsec per pixel. This is at about the low end of high resolution imaging. As can be expected, this image scale is stretching the seeing conditions of my site most of the time.

In practice, I can clearly see the effect of seeing on my images. Images reveal significantly more details on good nights (~2 arcsec seeing) while imaging was almost impossible on some of the worse nights. I would say my current image scale is already at about the limit for this site. Going for a smaller image scale would not yield images with more details.

The above has an important implication for this site. Resolution at this site is largely seeing limited. The theoretical resolving power of a 180mm refractor at 0.66 arcsec is more than adequate for the site's 2 arcsec seeing condition. A larger aperture telescope at this site may not yield higher resolution images, though it's higher light gathering power will help to reduce exposure time.

For example, say if I upgrade to a CDK17 reflector. I must switch to a larger pixel camera in order to lower the image scale. With a 16803 sensor at 9um pixels, the image scale becomes 0.63 arcsec per pixel. This clearly already exceeds the seeing capability of this site given my past year's experience. The number of usable imaging nights for this setup will be quite limited.

One good lesson I learned is that many sites do not support large telescopes for imaging. Often a small to moderate aperture refractor can already fully exploit the potential for a typical site. Larger instruments may reduce your exposure time, but this is less important for a remote observatory with decent percentage clear nights. For example, I can essentially cover all my image targets (suitable for the setup) within 18 months even though I am imaging at only f/7.2.

Having said the above, one not so obvious benefit a faster instrument can bring is that it can help you to make the most of your site's seeing condition. Everyone knows that we can stack many short exposures to emulate a long one. Therefore it may seem that with enough imaging time, a slow instrument will get identical results compared to a fast instrument. This is not quite so simple because such technique will introduce some blurring and hence reduce the resolution of the final image. In addition, additional noise will be introduced (mainly read noise) which can be important when your object is very faint (more on this later). A longer exposure is more blur than a shorter one because of the averaging effect of the random movements due to seeing. Your S/N ratio may be similar, but the image will be less sharp. I can clearly witness this effect when I stack well over 50 frames together. The dilemma is that as I increase the exposure to reduce noise, my images become more blurred. This can be partly offset by stronger processing since cleaner images can sustain more sharpening, but the return is diminishing. A faster instrument can help to avoid this problem since it requires shorter exposures to achieve the same S/N ratio image.

Another thing I noticed with my current setup is that seeing often becomes very poor when trying to image at around 40 degrees or below in altitude above horizon. This is another indicator that my current image scale is at about the limit of this site and I am largely limited to objects with high altitudes. Another lesson from this is that one should try to image near the meridian as much as possible, particularly if resolution is important for the target.

Another unexpected observation I have is that poor seeing can sometimes make color composites very difficult. For example, if my blue and green frames are exposed under good seeing while my red frames are under poor seeing, stars in my red frames will be significantly fatter than the other colors. After combining the channels, all my stars will have a red halo around them. This is extremely difficult to correct during image processing. I often end up retaking my RGB frames.

5. Internet access

For those of us who are used to fast and reliable internet access, we may take it for granted and do not realize the importance of a good communications link. This is actually vitally important for a remote observatory to allow both operational control and the download of images captured. Ironically, the more remote your site is, the more difficult (and often expensive) it is to have a good communicates link.

My site is about 9 km from the nearest small town. It is not extremely remote and fortunately have electricity, water supply and telephone network. However, since it is more than 5 km from the nearest exchange, ADSL internet access is not available. The recommended access for such remote sites is via satellite. This is what has been set up for this site for the past several years. This mode of access has several major problems.

Firstly, it is rather expensive and every byte counts. Even if we subscribe to the highest plan available (which is ridiculously expensive), it does not provide large enough data quota to enable us to download our images. Therefore, in the past, users have to copy images to hard disks and physically mail these hard disks once every several months. This is expensive, very cumbersome and there is a very long delay between image capture and processing. If something goes wrong with the image capture, it won't be discovered until several months later.

Secondly, satellite links have intrinsically very long lag times - typically one to several seconds vs tens of milliseconds for a broadband setup. This makes interactive access to the remote observatory very difficult and frustrating. In addition, the satellite link proves very unreliable with frequent drop outs and extended down times. Therefore, after an initial period of immense frustrations, I started to explore possible alternatives.

We have examine many different alternatives. At the end, we found a satisfactory solution by using 3G mobile data network. 3G coverage in Australia is not excellent and quite erratic throughout the country. At the site, there is no signal reception since the nearest tower is 9 km away and there is no direct line of sight. Using a high gain antenna, we obtained marginal reception at the house rooftop. But since signal is very weak, it is not reliable and data transmission speed is very low. Later we decided to take a bet and installed a better antenna about 10 meters above the rooftop. Luckily we obtained a decent reception with reliable and adequate performance.

The 3G link provides upload/download speeds of roughly 0.5mbps/2mbps. Although this is not very fast, it is adequate for our use which enables us to download all our daily captures within several hours. Interactive access is very usable with much shorter time lags. Reliability also improved significantly with much fewer drop outs and virtually no extended down times. Another welcomed side benefit is that our communications bill is even lower than before. We are fortunate that this simple solution has worked for us very well. Otherwise, it will significantly compromise the usability and enjoyment of this remote setup.

While we thought our problem is nailed, we were shocked one day about two months ago that it no longer works! The network seems fine, but we can no longer access our PCs remotely. We initially thought that the network operator has started to block port traffics which affected our usage. After much investigation and experimentation, we found the reason is that the network operator has started to allocate private IP addresses for all clients. These private IP addresses are not accessible from the outside world and hence we are doomed. After much search, we found another operator which offers public IP addresses. But unfortunately they do not offer an unlimited or high usage plan to allow us to download our images. At the end, we have to set up two 3G networks, one for interactive access and one for image download. Each PC is dual networked, which also creates numerous problems under Windows. After much efforts, I believe we have a workable solution now and hope the network operators do not make any drastic changes soon.

6. Local support

A remote observatory is a complex setup which involves many hardware and software components. Numerous problems can come up during both the initial setup stage and under normal operations. Therefore, local support is very important. Ideally, the local operator should have extensive experience in operating remote observatories who can give you good advices, help you with the setup, and provide good ongoing support in a timely manner. In addition, good hardware stores and machine shops should be available either on site or nearby for emergency services and ad hoc customization jobs.

My site is the front yard of the owner's home who lives there with his family. He has his own observatory and two other rented observatory at the same site. All these observatories are of similar constructions and has been operating for several years. Therefore, the owner has been able to provide sound advices and good support. However, the owner has another day time job and runs nightly sky tours at the property. This limits has ability to provide support only during late night hours and over the weekend. And the owner is the only person who can provide support with no other backups. Despite these limitations, I found that support at this site has been quite adequate.

The site is located near a very small town which only have a small hardware store and a local machine shop. The owner also does not have his own workshop nor a reasonable range of tools. I found that sometimes this is very inconvenient and makes unexpected repairs quite difficult. Though with careful planning, this is not a show stopper.

7. Off-axis guiding

Autoguiding is essential for long exposure deep sky imaging. Although some of the latest mounts have virtually no periodic errors and can compensate for many different types of tracking errors, autoguiding should provide the simplest and most reliable form of tracking correction. For example, instrument flexure and atmospheric refraction may change under different environmental conditions. Small errors may build up at very long exposures.

Reliable autoguiding is not difficult setup. The most common and difficult issue for autoguiding is differential flexure. Off-axis guiding (OAG) virtually eliminates this which makes autoguiding very reliable and simple to use. Some people opt for external guiding hoping that differential flexure is not significant for their setup given rigid mounting and short focal length. But very often they find that such a setup is not reliable and reverts to off-axis guiding at the end. For a remote setup, I strongly recommend using off-axis guiding at all times to ensure that guiding is accurate and reliable. I am glad that my camera has an integrated off-axis guider port and I never have any issues with autoguiding despite the fact that I am imaging at a fairly small pixel scale.

There are now many different autoguiding cameras available in the market, with a wide range of prices and performances. By design or by accident, I found that the StarlightXpress Lodestar is at present arguably the best autoguiding camera available on the market. It has many near perfect attributes such as small size, light weight, convenient mounting options, very sensitive, low noise, large pixel and large surface area sensor, very short back focus requirement, self-powered, relay outputs etc. Each of these attributes are very important on its own right.

For example, the small size and form factor greatly reduces the chances of physical obstructions with other components such as adapters and the camera since spaces are usually extremely tight with an OAG in place.

The very sensitive sensor with a large surface area virtually guarantees the existence of a suitable guide star within the field of view in any parts of the sky for most optical systems. For instance, I never have problem finding a good guide star on my f/7.2 system over the past year. This used to be a major problem for OAG systems. People used to employ star charts with projected guiding sensor frames and an electric angle rotator to help put a suitable guide star onto the guiding sensor. When this is necessary, automation becomes much more complex and less reliable. For slower systems, we also have the option to bin pixels since it is a CCD sensor (CMOS sensors cannot be binned).

The low noise sensor also helps to ensure guide stars are of high quality with high signal to noise ratio. A minor drawback of the Lodestar is that it does not have a shutter and hence cannot do auto-dark frames. When darks are not employed, autoguiding software may sometimes mistaken hot pixels as guide stars. Fortunately, we can prepare master bias and dark frames (for target guiding intervals) within MaxIm to implement full calibration and bad pixel mapping. Although such master darks may not have well matched temperature characteristics for each imaging session, they seem more than adequate in eliminating false guide stars due to hot pixels. Over the past year, I have never encountered false guide star problems with the use of master darks for my Lodestar.

Overall, I find the Lodestar an excellent autoguider and I highly recommend it for virtually all autoguiding configurations.

8. Tracking

With a properly setup OAG, a properly balanced instrument, and a good mount, I found that you can expect essentially perfect tracking most of the time. By this I mean perfect round stars even when viewed at 200-400% magnification on screen. I would say over 90% of my raw frames over the past year are like this.

We have examined the OAG above. We'll discuss the mount components and balance issue in a later section. Let's discuss some other tracking related issues here.

Although my favorite guiding software for manual sessions is PHD Guiding, I need to stick to MaxIm for my remote observatory because all the automations are implemented via ACP and MaxIm working together. There are many settings for MaxIm autoguiding, some of the more important ones are discussed below.

I have been using autoguiding intervals of 2-10 seconds (2 seconds most of the time). Based on my own experiences over the past several years, I found 2 seconds to be an optimal guiding interval for most situations. A guiding interval of less than a second is not recommended because of two reasons. Firstly, the star centroid may be much affected by seeing, producing false movements. Secondly, most mounts do not react well to fast short motions. They may not react or, even worse, may lead to oscillations or erratic motions. A long interval may affect the accuracy of tracking, particularly for mounts with large and sharp periodic errors. With a good mount, sometimes a longer guiding interval is preferred.

I have been using aggressiveness of 7 for both axis, smoothing out some fast corrections.

Anti-stiction has been enabled for the Dec axis with 3 cycles, preventing sudden reversal of Dec corrections. Min motion for both axis has been set to 0.02, translating to a min movement of 0.3 arcsec. This prevents too small motion commands be sent to the mount which may produce undesirable response from the mechanical system. Max motion for both axis has been set to 0.5, translating to a max movement of 7.5 arcsec. This prevents the mount from making large erroneous movements due to sudden atmospheric turbulences or other causes.

I have enabled dithering at the beginning, but disabled it after a few months. I found that it may sometimes take a long time for tracking to stabilize, particularly when the Dec axis has been perturbed. It is because if the perturbation caused a reversal in Dec motion, it can take a long time for the gear train to unwind it's backlash. Even worse, if the real tracking error is in the other direction, error will start to accumulate until backlash is unwind again. This incurs significant overheads and may sometimes lead to large tracking errors for some images.

Instead of enabling dithering, I choose to set periodic autofocus to every 30 minutes. Since each of my exposures are 10 minutes, the system will perform an autofocus every 3 frames. This means only three consecutive frames are not dithered. When stacking a large number of frames, the frames are effectively dithered automatically since the mount will never move back to the exact location after each autofocus operation.

9. Autofocus

Until not too many years ago, focusing an optical system for imaging (at least in the amateur world) has been a very challenging task, let alone performing it in an automated manner. It typically involves continuously fine tuning the focus of a star until the star image produces the highest intensity reading or the narrowest FWHM. Sometimes it is more an art than science, particularly when seeing is not very steady.

In 2001, Steve Brady and Larry Weber devised an accurate, yet robust method for autofocusing a star, which provides a critical missing link in automated imaging. At the same time they released their famous freeware, FocusMax , for focus automation. For an optical system with an appropriate electronic focuser, the software can achieve very accurate focus automatically within a very short time under a wide range of environmental conditions.

My telescope is equipped with a RoboFocus, which works very well with FocusMax and ACP in autofocusing. As mentioned earlier, I have configured the software to perform an autofocus operation every 30 minutes. I find this an appropriate setting which ensures that my focus shift due to temperature changes are mostly within tolerable limits, while at the same time without incurring excessive overheads in focusing time. Unfortunately the standard observation pack for ACP is in one hour units, I need to make minor customization so that it can schedule observations in 30 minute packs.

In an autofocus operation, ACP first slews to a particular location in the sky which is approximately 80 degrees in altitude due west. Then it looks up a nearby 6 magnitude star from the catalogue for autofocus. It also try to ensure that it is not a multiple star system. It slews to the star and starts autofocus. Once focused, it then slews back and continues imaging. The entire process is fully automated and takes about 3 minutes to complete, including all the slewing operations.

Although the process is generally very accurate and robust, it is not 100% foolproof. Sometimes when seeing is extremely poor, it can fail or give inaccurate results. Sometimes there may be errors in the star catalogue which results in a double star, accuracy will be somewhat compromised. Under such circumstances, limiting an observation pack to 30 minutes (instead of one hour) will limit the damage to 3 images, which I also find desirable.

Another fine tuning I have done is to focus using the red filter instead of the luminance filter. The reason is because with the luminance filter, each focus image only takes much less than a second. Such image can be severely distorted under poor seeing and hence producing inaccurate results. With a red filter, each focus image takes in the order of 1 second, which is more seeing immune and hence tend to produce more reliable results. When imaging with other filters, ACP will adjust the focus via a set of offsets defined for each filter. This usually produces very acceptable results.

Although RoboFocus has a temperature sensor and there is a version of FocusMax which supports temperature compensation, I choose not to employ it at this stage. There are two major reasons. Firstly, temperature compensation is currently performed automatically whenever temperature changes becomes larger than a user defined threshold. This may occur within an imaging session. Such focus movements may induce vibrations or image shifts and ruin an image in progress. Ideally all focus movements should only be performed in between images. This will require the cooperation between FocusMax and the image capture software. As of today, such integration is not yet available.

Secondly, I felt that relying on a single autofocus operation for a large number of images is too risky. As explained above, autofocus can fail or become inaccurate under some situations. I do not want such failures to affect a large number of images for the night. I believe the moderate price for periodic autofocus is a reasonable price worth paying.

10. Mount

For astro-imaging, a capable mount is the most critical prerequisite for success. It must be able to carry the load and track accurately across the sky to compensate for earth rotation. The amount of accuracy required is extremely high, therefore a well know advise is that you can never have too much a mount. This is literally quite true because a mount carrying a relatively light load will almost always perform better than carrying a heavy load approaching its limits.

Also considering possible upgrades in the future, I have opted for the largest mount I can reasonably buy in the market, the Astro-Physic 3600GTO. It is a massive mount which can easily carry over 130kg of loads. It is also very accurate and has many desirable features for remote operations. Below I'll discuss some of these features and how I used them.

The mount has a quoted periodic error of less than 5 arcsec peak-to-peak. My measurements were slightly higher than this. But with PEC enabled, I get a PE of less than 1 arcsec peak-to-peak, which is quite satisfactory for my purposes. Together with accurate polar alignment (<1 arcmin from the pole), I get very small and smooth tracking errors to start with. This makes autoguiding very easy and accurate, which explains the essentially perfect stars on most of my images.

Initially my tracking results were not very satisfactory. I get varied results across different parts of the sky. I originally blamed this on the cable dragging, seeing or flexure. At the end I found that this is all due to imperfect balance of the system.

Unlike the Paramounts, Astro-Physics mounts employ clutches. There are advantages and disadvantages to this approach. One major advantage is that a clutch can slip. Therefore if the mount hits the pier or some other obstacles, the clutch can slip and avoids serious damages to the system. Another advantage is that clutch has friction which makes it less vulnerable to vibrations under wind or other perturbations. Another minor advantage is that balancing can be easily performed without the need to disengage the worm gears.

One disadvantage is that it is much harder to "feel" the correct balance of the system since there are significant frictions. This is particularly so for the 3600GTO. When the scope is not balanced, tracking accuracy can be affected. With the suggestion of Astro-Physics, I used an electronic scale (the hook type) to balance the scope. By reading the amount of force needed to pull the scope in both directions, I can achieve very accurate balance for the system. After the system is properly balanced, tracking becomes very accurate and consistent across all parts of the sky.

The 3600GTO offers an option to add a set of precision encoders on the RA axis. This can virtually eliminate periodic error from the system. I have ordered this option with my mount. Unfortunately it has never worked properly and up till today, we still cannot figure out the reason for its failure. I am still working with the manufacturer on the problem hoping one day it can be resolved. Despite this, the mount has worked flawlessly over the past year and has produced excellent results. For normal imaging, zero PE is not required. For special projects such as photometry or sky survey, this feature may be useful.

The 3600GTO also offers several other important features for remote operations. The most important being the home switches. This is a set of mechanical switches which allow the mount to find a defined home position. This feature is very important for remote operations since a mount without absolute encoders may become lost (lost sync with the sky) under rare occasions. When this happens, it may be extremely difficult to re-sync the mount remotely. Paramount can be homed, and this is one of the major reasons many people recommend Paramount for remote operations. Although the 3600GTO home switches are not very precise, they are adequate for the mount to re-sync to the sky when it gets lost. I have tried it a number of times, it has worked quite well.

The mount also features a set of limit switches which users can fine tune to define the extent the mount is allowed to track past meridian. I find that my setup can track past meridian by approximately one hour. When the mount hits these limits, tracking will stop automatically preventing equipment damages. Paramount has hardwired stops at meridian. Astro-Physics mounts' ability to track past meridian is a nice feature which virtually eliminates the imaging dead zone around meridian. The limit switches are nice safeguards against software failure or operator errors, preventing potential equipment damages.

Another very nice feature for the 3600GTO is through-the-mount cabling. It has a 4" opening in both axis, providing plenty of room for cables and connectors to feed through. This avoids dangling cables being accidentally caught when the mount slews. Unlike the Paramount, the 3600GTO do not have a central shaft which cables must wind against in the proper direction. There are therefore no risk of cables being bind tightly with the central shaft.

11. APO refractor for imaging

The TEC 180mm APO refractor has been my imaging telescope at the remote site over the past year. I did not acquire this telescope for the remote observatory, it just happens that it becomes available at that time. So I decided to give it a try. In hindsight, I find this scope an excellent match for this site. It has performed extremely well and in many ways exceeded my original expectations.

With a focal length of 1287mm, it is not very fast at f/7.2. Therefore I have to accumulate more than 10 hours of exposures for most objects. However, since my observatory is fully automated and the percentage clear nights for the site is quite high, I can image very efficiently. At present, I have gathered a total of about 120 objects that I would like to image using the current setup. I estimate that I should be able to cover all my targets within 15-18 months. Then I can change my setup (with different field of view and resolution) for more new targets. Therefore, I feel that this f ratio is very adequate for remote operations.

As mentioned earlier, I believe for my current setup, resolution is limited by the seeing of the site instead of the telescope. Upgrading to a larger scope likely will not result in higher resolution images. The main advantage will only be the higher light gathering power, which I do not really need. Therefore, I tend to believe the current scope already allows me to fully exploit the potential for this site.

With the current camera (8300 sensor, 5.4um pixels, 0.87 arcsec per pixel, 60 arcmin FOV), I am already imaging near the seeing limit of the site. After this, I'll likely change the camera to image some larger objects. For example, a KAI-11000 sensor with 9um pixels will provide 116 arcmin FOV at 1.44 arcsec per pixel image scale. It will open up new perspectives for me for the following year or so.

I found that imaging with an APO refractor is a joy and have many advantages. Firstly, it is very simple to setup and does not require much maintenance. There are no collimation or shift optics issues. Contrast is very high and there is no central obstruction. Therefore a refractor tend to produce cleaner and sharper images compared to a reflector of the same aperture. Based on my comparisons (of the final images produced), I believe the 7" refractor's imaging performance can be equivalent to a 12-14" reflector.

When comparing a refractor and a reflector, most people focused on resolution degradation due to central obstruction. I believe there are more factors at play. To a visual observer, one most obvious difference is the higher contrast image produced by the refractor. I believe this is also very important for imaging. Consider two images (one by a refractor and one by a reflector) having the same S/N level. S/N ratio for the brighter features in the images should be similar. However it is not the same for the faint features. The lower contrast reflector image means that some light has "spilled" over to the darker features. This is similar to a light-polluted sky and will introduce white noise to the dark features. Hence, S/N ratio for the darker features will be lower for the reflector image compared to the refractor image. Some people falsely believe that we can simply compensate by boosting the contrast during image processing. An experienced astro imager will know that this does not work because noise will be amplified during the process. Ultimately, S/N ratio is the most important factor which determines how much detail you can hope to pull out from an image. I believe this explains why an APO refractor can perform like a much larger reflector in imaging.

Another feature I like about a refractor is that star images are nice and round with little artifacts. Very often when I examine images produced by reflectors, stars were distorted in various ways, apart from the prominent spikes. Other than affecting the resolution of an image, they can be quite ugly and significantly affects the artistic value of the image. I believe these are largely due to imperfect collimation or optics movements.

The shielded OTA of a refractor is less prone to dust, moisture and oxidation. With only one surface exposed to air, it is easier to clean. My refractor does not have a dust cover. I have only cleaned it once over the past year, it does not feel too dirty and is still delivering reasonable results. Due to the shielded OTA, it virtually eliminates tube current issues. Dew prevention for a refractor is also much simpler to achieve. Since a refractor performs like a larger reflector, its smaller optics is less prone to thermal issues.

Having said that, a premium refractor is often much more expensive compared to a similarly sized reflector. It is also often slower at around f/7. Price for an APO refractor larger than around 8" can become astronomical!

To be continued: Part II