“Piggyback Astrophotography”

Presented at Astrofest 2006 by Jim Cuca (jcuca@comcast.net)

Equipment

With piggyback astrophotography, the image is taken through a camera lens, rather than a telescope. A telescope is usually used to support the camera/lens, while the telescope’s mount moves the optical system to compensate for the earth’s rotation. Minimum requirements for piggyback imaging are: telescope/mount with a clock drive; camera and lens; piggyback mount.

Telescope/mount: I use an 8” Meade LX200. It is a Schmidt-Cassegrain telescope, fork mounted to a drive base, with a motor which drives the telescope and attachments at the speed necessary to track the stars. Similar systems include the Meade LX90 and the Celestron CPC line. These systems are ideal for the beginner. They are reasonably priced, especially since the optical tube and the mount are sold as complete systems. They track well enough to permit unguided, long exposures when using wide-angle and normal lenses. Most have user-friendly go-to technology, and many include other useful features, such as periodic error correction and backlash compensation. They also have mounting screws at both ends of the OTA, which can be removed to attach a piggyback mount for the camera. Perhaps the most advantageous feature of the fork mounted systems is its ability to move across the meridian. Objects are at their highest elevation when crossing the meridian; higher elevation means better contrast and less sky fog, hence longer exposures are possible. German equatorial mounts do not track as easily across the meridian. It is necessary flip the mount when crossing the meridian, to avoid imbalance and striking the tripod or pier with the lens end of the telescope. There are, however, disadvantages to the fork mount, one of which is the need for an equatorial wedge. The wedge is placed between the drive base and tripod/pier and must be adjusted so that the fork arms are in line with the earth’s axis of rotation. In this configuration, the mount’s right ascension drive becomes a polar axis. Without a wedge, the right ascension motor will rotate around a false pole, resulting in field rotation (stars away from the center of the field will appear curved, rather than round). The German equatorial mount does not require a separate wedge. Using a polar finder scope, inserted through the mount, one can adjust the mount in RA and DEC for accurate alignment. Polar alignment with a high quality, through-the-mount, polar finder scope is much easier than using an equatorial wedge.

Equatorial wedges: The standard Meade and Celestron wedges are relatively inexpensive and are recommended for the beginner who is not sure he/she wants to make a sizeable investment in astrophotography. I used the standard Meade wedge for my first astrophoto. It worked well enough to produce an image which won first place in the beginner, deep sky category at Astrofest. However, the limitations of the standard wedge quickly became evident to me. Altitude is adjusted using a bolt which presses against a plate on the underside of the wedge. The contact area is very small. As altitude changes, the bolt tends to slip along the plate, causing the wedge itself to slip, undoing the adjustment. Fine adjustments in azimuth are hindered by the rough surface between the wedge and tripod. Most annoying, the standard wedge requires continual loosening and tightening of the knobs which hold the wedge in place.

Meade and Celestron offer superwedges in the $400-$500 range. They are sturdier, but still difficult to use. I have heard of users spending up to $200 on modifications to get the superwedge to work well. I decided to go in another direction and purchased an AMF wedge (www.aptastro.com). It costs about $650 but is well worth it. The altitude adjustment screw threads through an attachment firmly secured to the top half of the tilt plate; the screw itself does not contact the plate. There is no slippage when making adjustments, and the design seems a more efficient use of gravity. In azimuth, the wedge moves along a smooth bearing, permitting fine adjustments without backlash. Once secured to the tripod/pier, there is no need to loosen and tighten any knobs, when making altitude and azimuth adjustments. The wedge is rather heavy, but is also very sturdy and much less a source of vibration than the standard Meade wedge. I have also used the Milburn Wedge (www.milburnwedge.com). It is well constructed, sturdy, and easy to use. It is also cheaper than the AMF. I recommend either the AMF or the Milburn for those seeking a quality wedge.

Piggyback mounts: Here again, the standard Meade and Celestron products are functional but limited. They are secured using mounting screws at the eyepiece end of the OTA. The camera, attached to the rigid mount with a screw, has no freedom of movement; it may not be rotated for composition purposes. With the camera confined to the eyepiece end of the OTA, wide angle and normal lenses will pick up the obstruction from the other end of the OTA. Ideally, one should be able to move the camera up and down the OTA and rotate the camera to permit vertical shots and other orientations. The best product I have found is the Milburn piggyback mount (PBCM2). It consists of a Bogen 3025 tripod head on a slider, which can be moved along and secured to a dovetail rail, running on the topside (or underside) of the OTA. Depending on where the telescope is pointed, the weight of the camera and lens can be moved along the rail to correct imbalance in declination. When using wide-angle lenses, the camera may be moved forward to prevent obstruction from the OTA. The Bogen 3025 has three axes of movement (up-down, left-right, roll), allowing the camera to be oriented in any manner. Dovetail piggyback mounts are also available from Losmandy (www.losmandy.com).

Cameras: The camera must be of the single lens reflex design. It must allow for interchangeable lenses and manual focusing. It must have an exposure setting to permit the shutter to be kept open without draining the battery.

Film: I use the Nikon F3. It has all the necessary features, plus many extras, such as mirror lockup, interchangeable focusing screens, and time delay. It is built like a tank, at the expense of being one of the heavier 35mm film cameras. Prior and current Nikon generations, such as the F2, F4, and F5 have also been popular among astrophotographers. Among the current generation of Nikons, the FM3 seems a good choice for astrophotography. The Olympus OM-1 has been a favorite, but it has been out of production for so long, one has to question its reliability.

Digital: I use the 8 megapixel Canon 20Da. It has many useful features, such as the ability to shoot a series of exposures with a remote shutter control. After the exposure, the image and a histogram may be displayed on the LCD screen, allowing the user to select the optimum exposure parameters. The 20Da has a very useful live focusing feature. It accepts all Canon AE lenses (other lenses such as Nikon may be attached with appropriate adapters). I find the 20Da to have very little noise. The 20Da was developed for astrophotography and is no longer in production. The 20D is virtually the same camera, except for the live focusing feature. Many of the best DSLR images have been taken with earlier Canons, such as the 10D and the Rebel (300D). They are 6 megapixel cameras which can be purchased at very reasonable prices. Some astrophotographers have had success with the Nikon D70. All DSLRs have infrared filters which block out most hydrogen-alpha light. Those wishing to capture emission nebulae should consider having their camera modified with a different filter. Hutech provides this service for about $600 (www.sciencecenter.net/hutech). I had my 20Da modified and am very pleased with the results.

Polar Alignment

Accurate alignment of the telescope mount with the North celestial pole is arguably the single most important task in long exposure astrophotography. With good alignment, it is possible to take quality pictures, using “normal” and “wide-angle” camera lenses, without active guiding to correct errors in the mount’s drive motors. Without good alignment, even the most diligently guided image will have misshaped stars and blurred detail. To understand why this is so, I highly recommend an article by Bruce Johnston, located at www.members.aol.com/ccdastro/drift-align.htm. Some popular SCT scopes, like those made by Meade and Celestron, have polar alignment routines which use the scope’s software. Most scopes with German equatorial mounts can use a polar finder scope. Here is a simple process for rough polar alignment, applicable to any telescope:

1. Level your tripod as best you can. Ultimately, being level is not essential, but it will make the alignment process easier and faster, especially when going for precise alignment.

2. Before it gets dark, and before turning on the scope, manually move the telescope tube to 90 degrees declination and 00h right ascension (for a fork-mounted scope, the OTA will be parallel with the fork arms, and the eyepiece will point

downward.) Use a magnifying glass and the telescope's manual setting circles to be as precise as possible. Sloppiness in this step is a common source of alignment error.

3. Turn on the telescope and, using the manual setting circles, slew to a bright, conveniently located star with known coordinates. Center the star, and move the RA setting circle to the star's RA coordinate.

4. Using the manual setting circles, slew to Polaris, at Dec. +89.3 degrees, RA 02h 38m.

5. Adjust the mount or equatorial wedge to center Polaris in a medium or high power eyepiece.

This procedure should be sufficient for short exposures (e.g., 2-3 minutes) and short focal lengths. Experienced astrophotographers strive for more precise alignment, to permit longer exposures and the use optics with longer focal lengths. This is usually accomplished through a procedure called "drift alignment." With a perfectly aligned mount, stars viewed through a high-power eyepiece will not drift in declination. Drift alignment involves adjusting the mount until the stars do not drift in declination. Bruce Johnston's article, referenced above, is the most thorough explanation of drift alignment I have read. Here is a summary of the process;

1. Perform a rough alignment, as described above.

2. **Correct azimuth misalignment**: Locate a bright star near the celestial equator (Dec. 0 degrees) and near the meridian (if using a German equatorial mount, choose a star west of the meridian). Insert a high-power reticle eyepiece, and rotate it as necessary so the crosshairs are parallel with Dec and RA movement of the scope. Now, track the star's movement in declination . Ignore any movement in RA. If the star drifts *northward* in the field, the mount is pointed too far *west.* If the star drifts *southward*, the mount is pointed too far *east*. Adjust the azimuth of the mount or wedge to minimize the drift.

3. **Correct altitude misalignment**: Select a star near the celestial equator and 20-30 degrees above the eastern horizon and track its movement in declination. If the star moves *northward*, the mount is aimed too *high.* If it moves *southward*, the mount is aimed too *low.* Adjust the altitude of the mount or wedge to correct the misalignment. If you can't find a star near eastern horizon, select one in the west, and reverse the directions given above.

Unless the tripod and mount were very level at the start, adjustments in altitude and azimuth will affect each other. Thus, it is usually necessary to repeat steps 2 and 3 a few times to eliminate declination drift. Careful leveling at the outset will minimize the number of required iterations. Perform enough iterations until neither star drifts in declination for at least five minutes. This will be sufficient for even the most demanding exposures.

Here are some additional considerations:

*Defocusing the star will make the star larger and may make it easier to detect drift

*It is necessary to equate the directions given above with the apparent movement of the star in your particular optical instrument. For instance, “north” is generally “up” in the field of a reflecting type scope and “down” in a refractor. Again, Bruce Johnston explains this very well. It may require a little practice and patience to determine directions for your particular system.

*When tracking a star near the east or west horizon, for altitude alignment, it is necessary to reposition yourself and contort your head a little. Otherwise, the drift will appear diagonal, rather than up or down. Before tracking the star, rotate your reticle, if necessary, to make sure the crosshairs are parallel with Dec and RA movement.

*Don’t be discouraged if the drift alignment takes a long time. Even experienced astrophotographers can spend an hour or more to eliminate drift.

Tracking and Guiding

As the earth rotates on its axis, stars and other heavenly bodies appear to move from east to west. If we don’t compensate for this rotation, star images will be elongated, and other detailed will be smeared. To get sharp, round stars, the optics and camera must be attached to a polar aligned mount with a clock drive, which moves at the rotational rate of the earth, in the opposite direction. Fortunately, there are numerous telescopes and mounts available at reasonable prices to accomplish this task. Most of them track sufficiently well to permit sharp images when using wide-angle or normal camera lenses as the optics. This is why beginners are encouraged to start with the wide-field piggyback approach. All mounts have imperfections which cause errors in the drive rate. Unless you have an expensive, high-end mount, you will not get sharp images with focal lengths greater than about 100mm on 35mm film (~ 75mm on DSLR). Here are some suggestions to improve your mount’s performance:

- *Give your mount enough work*. Many scopes suffer from insufficient and infrequent usage. Don’t allow your scope to remain idle for long periods. If necessary, set it up indoors once a month or so, and let it run as long as possible. Shortly after the initial tests of my new LX200, I set it up in my den and let it run 12 hrs. per day for five straight days. The periodic error was still there when I went out again, but it was not as great, and the error seemed “smoother.”

- *Balance in right ascension.* Not much to this for the German equatorial mount. Balancing in RA is done by moving the counterweights along the shaft; it is an integral part of the telescope set up. For astrophotography, it is recommend that RA be *very slightly* imbalanced toward the east, so that any slack in the gears will be taken up by the normal westward rotation of the RA drive. Fork mounts do not have counterweight shafts. Moreover, most are inherently imbalanced toward the west (when facing south). This is because the declination motor is located on "western" fork arm. The user must improvise. Some attach bean bags with Velcro strips to various spots on the OTA. I use an ankle weight, with a Velcro strap, which I found at a sports equipment store. It wraps securely around the "eastern" fork arm of my 8" LX200. For my scope, a 11/2 lb. weight is sufficient to produce a very slight eastern imbalance.

- *Use periodic error correction.* Many scopes, like the LX200, can be "trained" to compensate for PE. Periodic error is caused by the RA drive moving too slow or fast. It is periodic because it is cyclical. To implement PEC, you use the appropriate keys on the telescope hand controller to increase or decrease the tracking speed, as necessary, to keep a star centered in a high power reticle eyepiece, throughout a full PE cycle; the cycles are usually 4 or 8 minutes. The mount remembers and replays your corrections (with some smoothing) in future cycles. PEC will not completely eliminate PE, but it will reduce it substantially. With PEC, unguided exposures are possible for telephoto lenses up to about 200mm.

Manual Guiding

Even with PEC, most mounts cannot track well enough for focal lengths larger than about 200mm. Active guiding is needed to further reduce the PE. With piggyback photography, the telescope may be used as a guide scope. A bright star near the center of the field is selected and centered in a high-power reticle eyepiece. Throughout the exposure, use the appropriate keys on the hand controller to keep the star centered in the eyepiece. Combined with PEC, manual guiding can eliminate enough error to permit the use of most long telephoto lenses. Here are some suggestions on manual guiding:

- Use PEC. It makes guiding much easier. With good PEC it is not necessary, or even recommended, to make guiding corrections continuously. It may be possible to go 10 seconds or more between corrections.

- If possible, select a slow guiding rate. My LX200 allows me to select guiding speed at various percentages of the sidereal rate. To prevent overcorrecting, I set the speed at 30-50% sidereal.

- Dim the intensity of the reticle. If the crosshairs are too bright, you may lose sight of the star.

- When guiding in declination, use backlash compensation, if your telescope has this feature. Delays in Dec movement (hysteresis) are common when reversing direction. Sometimes there can be a 10 second or longer delay for the scope to respond to your commands. Backlash compensation attempts to reduce this delay. I have not had much success with this feature on my LX200, but that may be a deficiency unique to my scope.

- Avoid declination backlash by guiding in RA only. This is what I do. The only requisite is precise polar alignment. I adjust my wedge to eliminate declination drift for five minutes, which, conveniently, is my typical DSLR exposure time. If there's no drift throughout the exposure, there's no need for any corrections. Thus, I only need to deal with RA error.

If you get hooked on astrophotography, you will eventually want an autoguider. This is a ccd camera, which takes snap shots of a guide star, notes its drift, and sends correction commands to the mount. I use the STV, made by Santa Barbara Instrument Group. It's a remarkable instrument. But it is expensive, and I did not buy mine until I was sure I wanted to make astrophotography a major pursuit. Autoguiders are not necessary when using short and medium focal length lenses, so I recommend the beginner become familiar with PEC and manual guiding before making such a big expenditure.

Exposure Times

Most of the subject matter in deep-space astrophotography consists of stars, nebulosity, and dust concentrations located hundreds and thousands of light years away. Long exposures are needed to record the faint light of deep-space. For film, exposure should be long enough for the sky background to be clearly distinguishable from the film base between frames. Astrophotographers are often cautioned to cut their own negatives and slides, because the photo lab may not be able to tell where one frame begins and another starts. If this is the case with your negatives/slides, you have not exposed long enough. The film will not scan well, and important faint detail will be lost. For digital cameras, long exposures are desirable to increase the signal-to-noise ratio. If the exposure is too short, faint detail will be lost amongst the noise. In deep-space photography, underexposure is a much more common problem than overexposure.

With few exceptions, I expose as long as possible, up to the "sky fog limit." Sky fog consists mostly of reflected city light, but even at remote sites there appears to be a faint natural skyglow. At some point in an exposure, sky fog will brighten the image background so much that the fainter stars become indistinguishable. At this point, the sky fog limit has been crossed. The sky fog limited exposure time depends on many factors, but chiefly sky darkness (e.g., limiting magnitude) and the elevation of the object. The sky fog limit is longer when the sky is dark and transparent and when imaging near the zenith. Based on my experience, I make the following generalizations:

Film: Because of its poor quantum efficiency, very long exposures are required for film. Probably the most popular film in use today is *Kodak Elite Chrome 200.* At f/4, 30 minutes is about the minimum exposure needed to build up sufficient density on the slide emulsion to reveal faint detail. Under mag. 7 skies, this should be within the sky fog limit, regardless of the object's altitude. At such sites, exposure with E200 at f/4 can go as long as 40-45 minutes. At city or suburban sites, 30 minutes will likely exceed the sky fog limit, regardless of altitude. A light pollution filter may be the only way to get a nice shot. Under medium dark (mag 6-6.5) rural skies, objects near the horizon may succumb to sky fog, but overhead shots can withstand 30 minutes. I have taken some nice film shots of Cygnus at such locations.

Fuji Provia 100. A film with great potential, but brutal exposure times. A minimum of 45 minutes at f/4 required for bright scenes like Sagittarius; 50-60 minutes for faint regions, like Scorpius.

Fuji Provia 400: 20-25 minutes required at f/4. I don't care for this film. It is grainy, and colors are drab and muted, compared to E200.

These are the currently produced films with which I am familiar. Note they are all slide films. There may be a couple other suitable films out there, but most of the good astrophotography films have been discontinued and are no longer available.

DSLR Cameras: Among the advantages of DSLR over film is greatly reduced exposure time. I have found 5 minutes at f/4 and ISO 800 ideal for most wide-angle deep-space piggyback shots. Best results are achieved by stacking multiple 5 minute shots. This will bring out faint detail by improving the signal-to-noise ratio. A total exposure time of 30 minutes is sufficient for brighter regions like Sagittarius. I found 30 minutes insufficient for Scorpius; my best result for this region was a stack of 12 shots, for a total exposure of 60 minutes. The great thing about the DSLR is you can change the ISO setting. While I normally shoot 5 minutes at ISO 800, similar results may be achieved by shooting 2.5 minutes at ISO 1600. This comes in handy when such things as wind, frequent airplanes, or mount problems interfere with longer exposures. Another advantage of the DSLR is instant feedback; you can tell immediately if your exposure is too long or too short. Higher end DSLRs, like the Canon 20D, display a histogram along with the photo. A histogram is a graph of the image's light across the brightness range of the camera. A good rule of the thumb is to expose so that the upward slope of the histogram begins ¼ to 1/3 of the way from the left end of the histogram. If the slope is too far to the left you have underexposed; if it's too far to the right, you run the risk of clipping off highlight detail and/or exceeding the sky fog limit.

So, there is no easy way to determine optimum exposure time. You must experiment with your own equipment and imaging site on various targets at different locations in the sky. Except for objects with a huge brightness range, like the Orion Nebula, it is probably best to err on the side of longer exposure. It's generally better to have too much data than too little. Sky fog can often be reduced with image processing software, like Photoshop. Nothing can be done for data that is not recorded in the first place.

Image Processing

Nearly all deep-space images can benefit from digital enhancement. Typically, astrophotos need increased contrast and brightening of the midtones. If you shoot film, the slides and negatives must be scanned and digitized. The most challenging aspect of film image enhancement may be getting a good scan. I have not found any place in Chicagoland capable of scanning astrophotos. Since I don't own a scanner, I send my slides/negatives to veteran astrophotographer, Tony Hallas (www.astrophoto.com), who scans the film to CD at high resolution. Once scanned, software, such as Photoshop, may be used to darken the background, increase contrast, and correct any color imbalance. Photoshop has a steep learning curve, but the basics can easily be learned from the CD book, "Photoshop for Astrophographers," by Jerry Lodgriguss (www.astropix.com). The author provides a step-by-step basic process, using a wide-angle deep-space image as the example.

DSLR processing involves many of the same principles as film, but there are some important differences. Most experienced astrophotographers shoot in the camera's RAW mode. The RAW image must be copied from the memory card onto the computer, so that software can convert the RAW image to a format suitable for processing (usually 16-bit TIF). If multiple exposures were taken, appropriate software is needed to combine them. I use ImagesPlus for RAW file conversion and combining multiple images. ImagesPlus is also excellent at applying dark frames to multiple images. Although I have not used Cyanogen's products, I am sure Maxim DL and MaxDSLR are more than up to these tasks.

A 16-bit TIF DSLR image, converted from RAW, is very dark. This is related to how the DSLR chip records light. The chip responds to light in a linear fashion, while film response is logarithmic. Accordingly, DSLR images require more aggressive contrast stretching than scanned film. I recommend the website of Steve Cannistra, for a superb tutorial on DSLR processing.

For me, image processing is the fun part of astrophotography. With the user in control of the software, contrast and color balance may be adjusted to personal preference, using commands such as "curves" and "levels." The hue, or tone, of individual colors may be altered with commands like "selective color." Masks and layers may be used to hide selected parts of an image, while increasing contrast. Blurring/smoothing can be applied to reduce noise. Unsharp masking can sharpen images which may appear soft or slightly out of focus. The possibilities are numerous, allowing full expression of the user's artistic tastes.

References/Sources of Information

Books:

Covington, Michael A., Astrophotography for the Amateur, 2nd Edition (1999).

Reeves, Robert, Wide-Field Astrophotography (1999)

Lodgriguss, Jerry, Photoshop for Astrophotographers (2003)

Mollise, Rod, Choosing and Using a Schmidt-Cassegrain Telescope (2003)

Due to the rapidly changing nature of astrophotography, there is no single, comprehensive written source which has kept up with the recent explosion of new technology and software. I have found the best sources to be the websites of individual astrophotographers. Here are some of my favorites:

Steve Cannistra: www.starrywonders.com

Tony Hallas: www.astrophoto.com

Mark Hanson: www.btlguce.digitalastro.net

Jerry Lodriguss: www.astropix.com

Philip Perkins: www.astrocruise.com

Great sources of current information can be found in various Yahoo groups. The groups allow you to enter into discussions with other astrophotographers on matters of technique and equipment. DSLR users should try the "digital_astro" group. Yahoo user groups exist for most major telescopes and cameras. Since I purchased my Canon 20Da, I have found "Canon_DSLR-Digital-Astro" invaluable. Do you use a Meade telescope? If so, check out "MAPUG." There is even a Yahoo group dedicated to polar alignment!

Nearly every month the magazines "Sky and Telescope" and "Astronomy" contain articles intended to help amateurs improve their techniques.