**Astrophotography AST 244**

**HOWTO**

*Ben Moore, March 2020*

Read this entire HOWTO. Read the manuals for all the software below and for the equipment you will take, especially the telescope mount manuals.

You will either have the Takahashi 102mm refractor (TSA-102) with the EM-11 mount, or the Williams Optics Star 71mm with the Skywatcher HEQ5 pro mount. You can find manuals for this equipment online.

We have provided with the equipment a windows laptop with some of the software installed.

If you use your own laptop then you need to install:
-the latest ascom V6 platform
https://ascom-standards.org/

-the ascom takahashi temma ascom driver or the skywatcher ascom driver & EQMOD software depending on which telescope mount you take. You can find links to these here:
https://ascom-standards.org/Downloads/ScopeDrivers.htm

-Moravian SIPS – for taking the images and for autoguiding
-Moravian CCD Gx CCD camera drivers (G2 is the main camera, G0 is the autoguide camera)
https://www.gxccd.com/cat?id=5&lang=409

-PHD2 for drift alignment and for autoguiding
https://openphdguiding.org/

-'Cartes du Ciel' a star chart for controlling and pointing the telescope
https://www.ap-i.net/skychart/en/start

(the skywatcher mount can also be controlled with a handset which has a catalogue of objects built in, however, you need to use 'cartes du ciel' rather than the handset to control the telescope)
-serialport2USB driver (for the cable connecting the mount to the laptop, may already be installed).

Before you take the telescope out into the field for the first time, you should set it up inside at your home. Note that you can only test the CCD camera at twilight or in a dimly lit room – the CCD is very sensitive and bright daylight (or the Moon) is too bright and may damage the sensor. You can test the CCD at dusk by taking 0.1 second exposures through a window (the shortest it can take). For reference, your camera during daylight would normally take 1/60$^{th}$ second exposures or shorter.

Plan what you want to observe in advance, read about celestial coordinates and astrophotography with equatorial mounts. Charge up the batteries and the laptop. Setup everything indoors first and check the laptop can control the telescope and connect to the CCD cameras.

**Setting up the telescope and alignment**

The telescopes equatorial mount turns exactly opposite to Earth's rotation so that you can take a long exposure of a fixed point on the celestial sphere. But the mount must be pointed precisely towards Earth's rotational axis for this to work.

The telescope alignment is made by pointing the rotational axis of the mount at the North Celestial Pole. This is near the 'North star' Polaris – over a sidereal day the Polaris rotates completely around this point. Begin before dark so you can see what you are doing and so you can adjust the finder scope to point in the same direction as the telescope. The entire process should take around one hour. That's ok, it takes about an hour for the telescope to cool down and reach optimum performance. You may need to refocus as the optical tube settles to the new temperature. For further information read this:
http://themcdonalds.net/richard/wp/polar-alignment-of-your-equatorial-mount/

1. Place the tripod so that with the mount, it points to the North. Use a bubble level (on the mount or on your phone) to ensure it is roughly level
2. Fix the mount to the tripod with the screw underneath. Use the metal spreader piece to block the tripod legs open
3. Do not connect the batteries to anything yet
4. Fix the telescope tube to the mount using the tube holder. Do not over tighten
5. Attach or extend the long metal pole from the mount for the counterweights
6. Attached one or two counterweights as necessary
7. Insert the small finder scope into the holder on the main tube
8. Attach a wide field eyepiece to the telescope (you may need one or two extension tubes) and take off all the lens caps, extend the tube light protection cover
9. Balance the telescope on the two axes (right ascension [ra] and declination [dec]): lock the dec lever and open the ra lever. slide the telescope along its holder until it balances. then unlock the dec lever and lock the ra lever, adjust the position of the counterweights to balance the second rotational axis. Note that when you add or remove equipment attached to the telescope it will need to be rebalanced. if the telescope is not accurately balanced then it puts stress on the gears and it will not track accurately and it will wear out the gears.
10. Align the tube and secondary finder by focussing on a distant object/tree/building/planet through the telescope tube (easiest at twilight) - adjust the position of wide field secondary finder (mounted on the tube) so the same object is in the crosshairs as is visible in the centre of both scopes.

**For the Takahashi TSA102 telescope & EM-11 mount:**

- Remove the small covers on the mount (top and bottom that point towards Polaris) so that you can look through the internal telescope at Polaris in the North. you may need to rotate the telescope so the optical pathway is clear
- Plug in the remote hand control to the mount
- Attach the power cable from the mount to the **battery 12V port!!**
- Turn on the mount switch – this will illuminate the internal telescope
- Turn the RA axis so that the large cross markings are vertical.

- Polaris needs to be placed on the 2016 circle at the correct hour angle. 0hr is at the bottom by definition, and the hours run anti-clockwise. Subtract the RA of Polaris (2hr 52mins in 2016) from the local sidereal time. or use an app/software to show you where Polaris should be on this circle
- Position Polaris at the correct hour by turning the altitude and azimuth knobs. If all is correct, the arrows should point at the constellations Ursa Major and Cassiopeia. (You can also roughly align the mount by turning the telescope mount until these constellations are in the correct place.) Now the mount is roughly aligned.
- I recommend fine tuning your alignment by using the drift technique below.

**For the Skywatcher mount with the Williams star optic 71mm small telescope**

- follow the same steps as above, but read the EQ5 pro mount manual for more details.

**GOTO software**

Now the mount is aligned and will turn in the correct axis at the correct rate automatically as soon as the telescope mount is switched on. In order to point the telescope in the correct place in the sky use the Cartes du Ciel software. For this to work, the software needs to know where the telescope is pointing and the Ascom mount control drivers and software need to be installed on your laptop. For the Skywatcher mount you can also do this with the GOTO handset.

11. Check the date and time on the laptop – it may not be correct since it does not auto-update.
12. Connect your laptop to the mount using the rs232 to USB cable. For the Skywatcher EQ5 pro mount, connect to the socket labelled handset.
13. Turn on the mount power switch, it will begin slowly moving with the stars automatically.
14. Start the 'cartes du ciel' and connect the telescope to the laptop:
    Under telescope settings menu make sure ASCOM is selected. Under telescope menu 'connect to telescope', make sure the correct telescope driver is selected (takahashi or EQMOD). Then enter properties/configure tab. Enter the correct com port which you can find under windows control panel for the "devices and printers". When you connect the telescope a new device should appear. Right click, properties, hardware and you will see the com port). Click connect telescope. An ASCOM telescope control window should pop up with NSEW controls and lots of options such as mount drive speed for slewing – set to max. Enter your longitude and latitude if it is an option. You may see some options about how the telescope is set up – if the object you want to observe is East of the meridian then start with the telescope on the West side of the mount as viewed standing North of the mount. If object is in the West, start with telescope on the East. Unpark telescope. Test connection by moving telescope with North/South/East/West buttons. Telescope should move. If not, read the guides again – there is a lot of info online about this and all other steps.
15. Initialise (sync) the telescope (tell the software where the telescope is pointed) by moving the telescope manually to a star you recognise:
    Loosen the RA and DEC clamps and point the telescope at a bright star you know (well away from Polaris), you can also use the NESW controls in the ASCOM software or the handset. Find that star in Cartes du Ciel and press the sync button by right clicking on that star and

using the drop down menu. The crosshairs in the software should appear on that star. This enables the software to know where your telescope is pointing.

16. Find another nearby bright star that you can recognise easily on the skychart screen and click the mouse on the object, a window pops up with the name and coordinates. Right click and 'slew' to object, and the telescope should move to the object and the crosshairs should appear on the object
17. If it worked, you can see your new target through the eyepiece; congratulations! If you see that the telescope is moving in the wrong direction click the "stop button" and check all the steps again.
18. If the star is not quite in the centre of the field your polar alignment was not so accurate and you may need to do that again, or do a drift alignment (continue reading) for more accuracy.
19. Take off the eyepiece and carefully secure the CCD camera to the telescope tube.
20. Attach the small autoguider camera to the off axis connector on the front of the main CCD camera
21. Repeat step 9 to re-balance the tube because the CCD camera is heavier than the eyepiece.
22. Repeat step 16 to sync the telescope with the laptop control software.

**CCD Camera**

You can test the CCD camera at twilight or in a dimly lit room, but not in the daytime outside. The shortest exposure is 0.1 seconds and the CCD camera is very sensitive and the telescope collects ~100 times as much light as a small camera (which would need just 1/60$^{th}$ second exposure or shorter during daylight). If the resulting image in SIPS is black and shows pixel values of 65,535 (the maximum), then you have overexposed. When you see your first successful image it might look awful, with noise and gradients across the image. That's why you need to take "darks" and "flats" to subtract noise and create a uniform final image.

1. Connect the CCD camera to the battery **12V port!!**
2. Connect the CCD camera to your computer using the USB cable (under devices and printers you should see a new device appear).
3. Start the camera software (SIPS) on the laptop, under tools menu, select the ccd camera G2 as the imaging camera (it should show up in the list once you click 'scan')
4. Set the CCD temperature to cool down to 20 degrees below the ambient temperature
5. Focus using the "focus tab" by first selecting a region of the frame with contains a visible object or bright star and turn the focus wheels on the tube to bring the image into focus. This takes patience since if it is a long way from focus the image will appear just black and noisy or you may see a single white filled circle – this is the out of focus tube view. You can speed up the focusing by clicking on the 'binning' tab and choosing 3x3 for example. For fine adjustment, use the Bahtinov Mask on the front of the tube, and bring the three diffraction spikes of a star into alignment: see https://en.wikipedia.org/wiki/Bahtinov_mask
6. If you wish to refine the accuracy of the alignment you should now follow the steps at the end of these notes for accurate polar alignment using the "declination drift technique". If you have made a reasonably accurate polar alignment and use the autoguider correctly, you

will not need to do this but the telescope will track more accurately if you do. And if you cannot get the autoguiding to work properly, this step is essential.

**Troubleshooting**

You will need to use either a second laptop, or the USB multi-port adapter since you will need to connect 3 USB devices (the mount, the main CCD camera and the guide camera). Sometimes, cameras are not recognised, the goto software fails to recognise the mount or connections are lost. That's typical with USB devices and these problems are usually solved by unplugging/replugging the cables and/or restarting the laptop or software.

**Flat field frames**

Flat field frames are used to correct problems in the optical path, including dust, vignetting and internal reflections. Any change in the optical path, such as changing the camera orientation, will require a new flat field frame. To obtain the best possible flat field frames would mean taking it at the same conditions as the light and dark frames. To take flat field frames, first focus and then point the telescope to an evenly illuminated surface. Flat field frames can be taken from the twilight sky or with a clean white cloth placed over the tube to reduce light or with the led illuminated white panels. The exposure time has to be chosen in such a way that the intensity level reached approximately 50% of the maximum. Do not over expose and take several flat field images at different exposure times. These typically need short exposure times – if the photo count is over 65,535 you have overexposed.

**Dark frames**

The purpose of a dark frame is to remove the non-image related thermal and electronic noise that the CCD generated when capturing photons. It also removes imperfections of the chip, such as dead pixels. Since we are capturing the build up of thermal and electronic noise, it is important to match the dark frame to the same conditions as the light frame, this should include the same duration of exposure, chip temperature, gain, brightness and contrast. Dark frames can be taken by covering the telescope with its lens cap and take at least 10 images with the same exposure length as the light frames. With these dark frames you can generate a master dark frame.

**Your final calibrated image is then equal to (raw - dark)/[(flat-dark)*(mean flat – mean dark)]**

**Autoguiding**

It is very difficult to perfectly align a telescope by only using the internal scope and positioning Polaris, and the tracking will drift over time leading to star trails. The declination drift technique below will give a much more accurate alignment and may be sufficient for taking data for exposures of tens of minutes. Otherwise you will have to take many short exposures and stack them which is a pain. However, there is a separate guide camera (G0 Moravian) which takes light from the edge of the field via an off axis prism adapter. I recommend using PHD2 for autoguiding but you can also do this within SIPS. The SIPS or PhD2 software takes a bright star in this image and guides the telescope automatically, keeping the star in the same position by sending control signals back to the mount. Read the manuals or watch youtube guides. You can always resort to using a more accurate polar alignment method as detailed below.

7. Take a one minute exposure with the ccd camera on its highest resolution. You will probably see that the stars drift slightly across the image because polar alignment with the internal scope is never perfectly accurate. The autoguider will correct for this drift by searching for bright stars and guiding the mount keeping the star fixed in place
8. Do not use any cables in the guide control port of the mount, the computer will guide the mount via the usb2rs232/serial cable.
9. Attach the USB cable from the laptop to this camera, add this G0 camera as an autoguider in the tools menu of SIPS or PHD2. I personally prefer PHD2 for guiding. Test the autoguiding by pointing telescope at some bright stars.
10. PHD2 rough guide: connect to the camera and the mount (select G0 camera and the correct mount). Start taking short test exposures with the autoguide camera. You may need to rotate the camera to find a bright star in the field of view. Click on a visible bright star. You will see a window with the full width half maximum (FWHM) of the star – that's how sharp the light profile is. You can focus the guide camera by making this image sharp and the FWHM small. You then need to stop taking focus exposures and calibrate the software. Click on a star, shift-click autoguide/calibration. The software will automatically move the mount small amounts in various directions so it can learn the orientation of your camera. Then it should start guiding. There are youtube videos and a detailed manual for PHD2 online.
11. The software will guide the telescope by keeping the brightest star in a fixed position. If the telescope is not reasonably well aligned to the North star then the corrections may be too large and the autoguiding may fail. PHD2 shows you the corrections and errors. Take another ~one minute exposure with the main camera – if your stars are points of light rather than short trails of light then you have succeeded and you are now ready to take data! Congratulations!!
12. Take many long exposures using each of the 4 filters. You will stack them all together later.

**Taking and reducing the data**

Keep a log of your observing, date, place, start and end time of each exposure etc. Take 'darks' and 'flats' (to subtract bad pixels and image gradients).

Here is a good tutorial on CCD imaging: http://www.skyandtelescope.com/astronomy-resources/astrophotography-tips/the-abcs-of-ccd-imaging/

Take some short exposures of a star, so that you can measure the 'astronomical seeing' that night. Point the telescope at your chosen object and take your long exposures with the different filters. The filter in position 1 is a luminance filter (it lets all the light through), use this to set the brightness of your final image. Use image processing software e.g. the CCD SIPS camera software or other software (see below) to process your images (subtracting flat fields, combining exposures etc).

A good free software tool for aligning/calibration/stacking images is deepskystacker: deepskystacker.free.fr (the FAQ on this website will explain the use of dark and flat fields etc). For an overview to all the image calibration and processing, read this online article: https://iso.500px.com/deep-sky-photography-guide-part-3/

The contrast, colours etc can also be manipulated with a program such as photoshop, or free astrophotography software such as IRIS http://www.astrosurf.com/buil/us/iris/iris.htm or GIMP www.gimp.org etc.

Please also read these articles 2a-3e on image processing and the true colour of stars and nebulae, this will also be very useful in your report when you describe the "astrophysics" of your image: http://www.clarkvision.com/articles/

Can also read r/astrophotography or a good book on astrophotography (e.g. "Making every photon count" by Steve Richards).

Here is a nice summary of how to enhance the real star colours: http://www.astropix.com/html/j_digit/starcolr.html

**Precise Polar Alignment – Declination Drift Technique**

For long exposure imaging, the alignment using Polaris will not be perfect and stars will slowly drift across the image. The declination drift method allows a much more accurate alignment by monitoring the drift of selected stars. The drift of each star tells you how far away the polar axis is pointing from the true celestial pole and in what direction. Although declination drift is simple and straight-forward, it requires time and patience to complete when first attempted. The declination drift method should be done after the above polar alignment steps have been completed.

You will need to choose two bright stars, one near the eastern or western horizon and one due south near the meridian. Both stars should be near the celestial equator. While monitoring a star on the southern meridian, any misalignment in the east-west direction is revealed. This is corrected by moving the mount in its azimuthal direction (i.e. east or west, or clockwise/anticlockwise). While monitoring a star near the east or west horizon, any misalignment in the north-south direction is revealed. This is corrected by moving the mount in the declination direction (i.e. up or down). The telescope mount manual will describe how to move the mount in these directions.

For drift aligning I use the software tool 'drift align' within PhD2. It is important to read the online guide to this process and follow the steps there:
https://openphdguiding.org/tutorial-drift-alignment-with-phd2/

Here are my own notes: After connecting the camera (either the guider or the main camera) to PhD2, you can start taking short exposures of about 1 second. You should see some stars in the image. If they are not in focus, then refocus. Then you can click the calibrate button – the software then moves the telescope in small amounts in different directions so the software can figure out automatically which way the image moves in the CCD frame (the software does not know in advance the orientation of the camera!). Then you can click the drift align tool button. The software will tell you to find a star in the South near the meridian and near the celestial equator. Within 20 degrees of that point works fine. If you don't know where the celestial equator is, then read about that first. Click on your star so that a green box surrounds it. If the star is blurry then the camera or autoguiding camera are not in focus. After a minute or so the software shows a red line that track the alignment errors. Follow the steps in the manual to try to correct those by moving the azimuth screws on the mount to bring the red line horizontal. Its trial and error which way you move those. Keep a note of what works in the 'notes' section of the drift tool. If you are lucky, someone else has already done that! Once the red line is nearly horizontal, click done, and the software will tell you to point at a star near the East or West horizon. Then you repeat the steps to get the red line as flat as possible by moving the dec lever on the mount to raise or lower the angle at which the mount is pointed. Again, its trial and error which way the telescope mount should be moved. For extra precision, you can repeat the steps by returning to a star on the Southern meridian and then again on the East or West horizon.

Once the drift has been eliminated, the telescope is very accurately aligned. Try not to bump into the mount! You can now do prime focus deep-sky astrophotography for long exposure times. The laptop receives the signal from the autoguider via the USB cable, the software SIPS or PhD2 sends small corrections back to the mount via the USB2serial/rs232 cable. If the mount is not reasonably well aligned to begin with, the corrections may be too large to control the mount and the guiding software will give a lot of error warnings.