Sky-Watcher EQ6-Pro and Celestron C11 imaging and guiding at f6 via OAG

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1 Aims

- To get consistently round stars during imaging using a Celestron C11 with an Off Axis Guider (OAG) and f6.3 focal reducer working at 1762mm focal length;
- Use the PHD2 polar drift align and guide assistant tools to assist in obtaining sufficient accuracy so that no trailing of stars occur during deep sky exposures;
- To accurately collimate, balance and polar align;
- Minimize RA and Dec backlash;
- Train EQMOD PEC.

2 Overview

The principal aim is to get consistent round stars during imaging and guiding at f6.3 with my Celestron C11 (a focal length on 1762mm) with my old EQ6-Pro (i.e. not the EQ6R and no belt drive upgrade).

Main diagnostic tools will be the drift align and guide assistant in PHD2 and the infallible test of eyeballing an un-guided image.

To get best results when using the PHD2 guide assistant run for up to 10 minutes. The computed polar alignment error is sensitive to the current scope declination and to get the most accurate measurement you should point the scope to within a few degrees of the celestial equator, which is also the same area you should use for calibration during the process.

The EQ6-Pro worm period is 479 secs (7.9 mins) so a 10 minute PHD2 guide assistant run will include more than a full rotation.

My f6.3 imaging and guiding configuration is shown in the figure below and consists of a Celestron OAG, ASI120MM guide camera, ZWO USB powered filter wheel and an Atik 383L+ CCD camera.

The Celestron f6.3 focal reducer has a focal length of 285mm. For it to work at f6.3 the distance from the the focal reducer back element to the CCD chip must be 105mm.

Distance 'A' and 'B' must be the same so that the guide and imaging CCD's can be focused together.

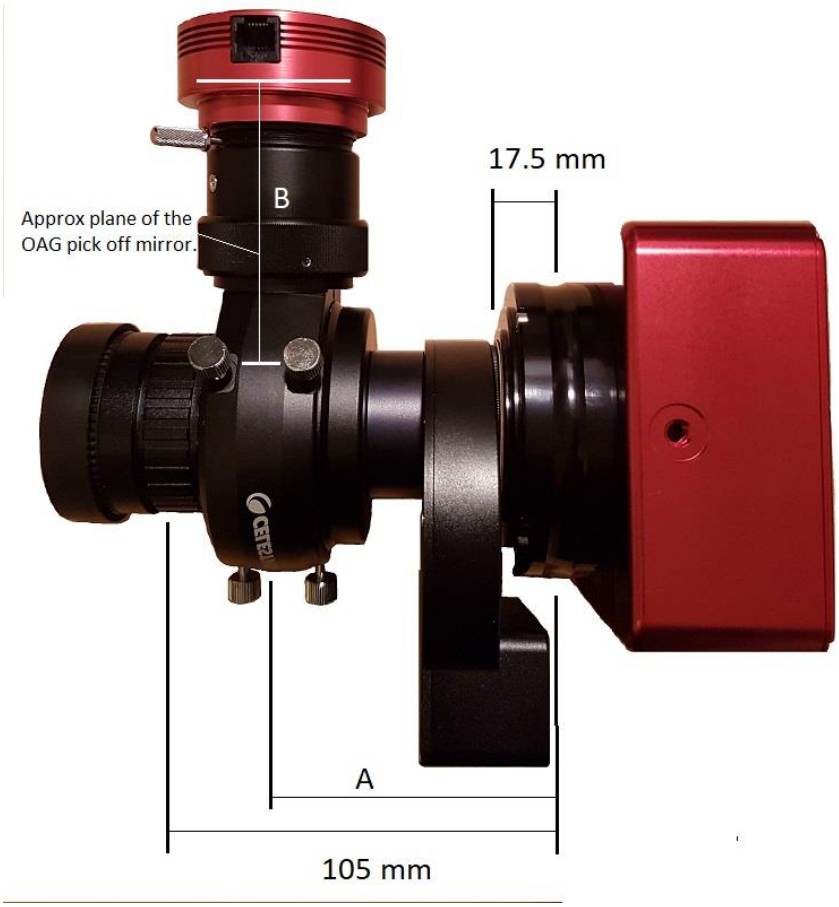


Figure 1 - Imaging and guide configuration for f6.3

When running the PHD2 guide assistant and drift align tools, and also for collimation, I use a ASI178MM camera attached in a ‘straight through’ configuration as shown in the figure below. I also run the camera bin 2 ensuring that the PHD2 camera profile parameters are set as such.

Figure 2 - ASI178MM for PHD2 use

3 Summary

If you don't want to read the details in the subsequent sections, here is a summary.

3.1 Activities and results

Activity	Result
Run 1 - I hadn't performed any maintenance on my EQ6-Pro for at least a year	
Imaging and guiding at f6.3	Starting to get elongated stars in RA during guided exposures, assumption is that this is due to the drift limiting exposure being too short caused by mechanical issues building up with the mount as I haven't performed any servicing on the mount for a long time.
Re-balanced scope	
Run PHD2 Guide Assistant (ASI178MM @ f10, bin 2)	RA Periodic error 10". I don't believe this PHD2 result; it's far too good for an old EQ6!
	RA drift rate: +0.91" / min
	Drift limiting exposure 0.9s (too short)
	Dec backlash: 4961ms, 86" (too high)
	Polar align error: 4.3' (needs to be better)
Eyeball an Image without guiding	Shows clear drift (star elongation) in RA direction which confirms the PHD2 guide assistant results.
Run 2 at f10 – Adjust mechanical backlash	
Collimated scope	Needed to be done, so why not now.
Mechanical backlash adjusted for RA and Dec	Procedure very well documented by Astro Baby here: https://www.astro-baby.com/EQ6%20rebuild%20guide/EQ6%20worm%20alignment.htm
PHD2 Guide Assistant (ASI178MM @ f10, bin 2)	RA periodic error 25". This is far more believable, OK for an old EQ6.
	RA drift rate: -1.16" / min
	Drift limiting exposure 0.7s (too short)
	Dec backlash: 826ms, 11.9" (< 1s, much better)
	Polar align error: 5.4' (should be better – needs refining)
Run 3 at f10 – Refine polar alignment	
Leveled pier and mount	See figures in section 6 below for details.
Refine polar alignment using PHD2 drift	Polar align error: 0.18'
PHD2 Guide Assistant (ASI178MM @ f10, bin 2)	RA Periodic error 18" (acceptable)
	RA drift rate: -0.74" / min (acceptable)
	Drift limiting exposure 1.2s (just about acceptable)
	Dec backlash: 788ms, 11.5" (acceptable)
	Polar align error: 1.3' (acceptable)
Run 4 at f6 – No mechanical adjustments made since the Run 3 test above at f10 but now working at f6 with PHD settings adjusted accordingly	
Check polar alignment using PHD2 drift – no adjustment made	Polar align error: 0.26' (value about the same as previous polar alignment check made at f10 above)
PHD2 Guide Assistant (ASI178MM @ f6, bin 2)	RA Periodic error 18" (same as guide assistant when at f10)
	RA drift rate: -1.48" / min
	Drift limiting exposure 0.9s
	Dec backlash: 1056ms, 11.5"
	Polar align error: 1.7' (about the same as guide assistant when at f10)

Activity	Result
Run 5 at f6 – Trained EQMOD PEC	
Trained EQMOD PEC	Trained for 40 minutes (5 cycles)
Run 6 at f6 – Guide assistant with EQMOD PEC trained	
PHD2 Guide Assistant (ASI178MM @ f6, bin 2)	RA Periodic error 25” (Guide graph is flatter so this may be a bit spurious)
	RA drift rate: -1.7” / min (acceptable)
	Drift limiting exposure 1.3s (acceptable)
	Polar align error: 1.3’ (acceptable))
Eyeball an Image without guiding	Very little drift observable in 2 minutes.

3.2 Conclusions

All in all I would declare the telescope, mount and software tweaks a success as the image quality is visually superior during Run 5 compared to Run 1.

It should be kept in mind that the ultimate constraint on my setup is the engineering tolerances (or lack of them) on my old EQ6-Pro mount, but I reckon the imaging results are more than acceptable for this mount.

The essential final configuration figures are as follows.

- PHD2 guiding at f6 with a focal length of 1664mm via Celestron C11 scope, ASI120MM guide camera, Celestron OAG and Celestron f6.3 focal reducer. This imaging setup is working at f6 rather than f6.3 because the Celestron f6.3 focal reducer to imaging chip distance is 115mm in my setup (see Appendix for details);
- Polar alignment is reported as between 1 and 1.7’;
- RA peak to peak is reported as between 10” and 25” (more towards the 25” end would be my estimate);
- Atik 383L+ working at 0.67 arc secs / pixel at bin 1 (slight oversampling);
- Atik 383L+ FOV approximately 37’ by 28’;
- EQMOD pulse guide for RA and Dec both set to 0.7x;
- PHD2 RA oscillation for the test image was 0.37 which is acceptable (PHD2 documentation states that ideal is 0.3 to 0.4);
- PHD2 RMS RA figure for the test image was 0.29” which is acceptable when imaging at 0.67 arc secs / pixel;
- PHD2 RMS Dec figure for the test image was 0.17” which is acceptable when imaging at 0.67 arc secs / pixel;
- PHD2 guide exposure of 2.5 seconds;
- No star trailing in images as you would expect with the PHD2 stats above.

4 Imaging Test Run 1

The first image below is an unguided 5 min exposure on my C11 at f10 and shows a definite drift resulting in elongated stars. The second photo show trails due to slewing in RA during an exposure to confirm that the star drift in the 1st image is predominately in the RA plane of movement.

Figure 3 - Run 1 test image showing star trailing

Figure 4 - Run 1 test image showing RA slew motion

PHD2 guiding assistant results are as shown below:-

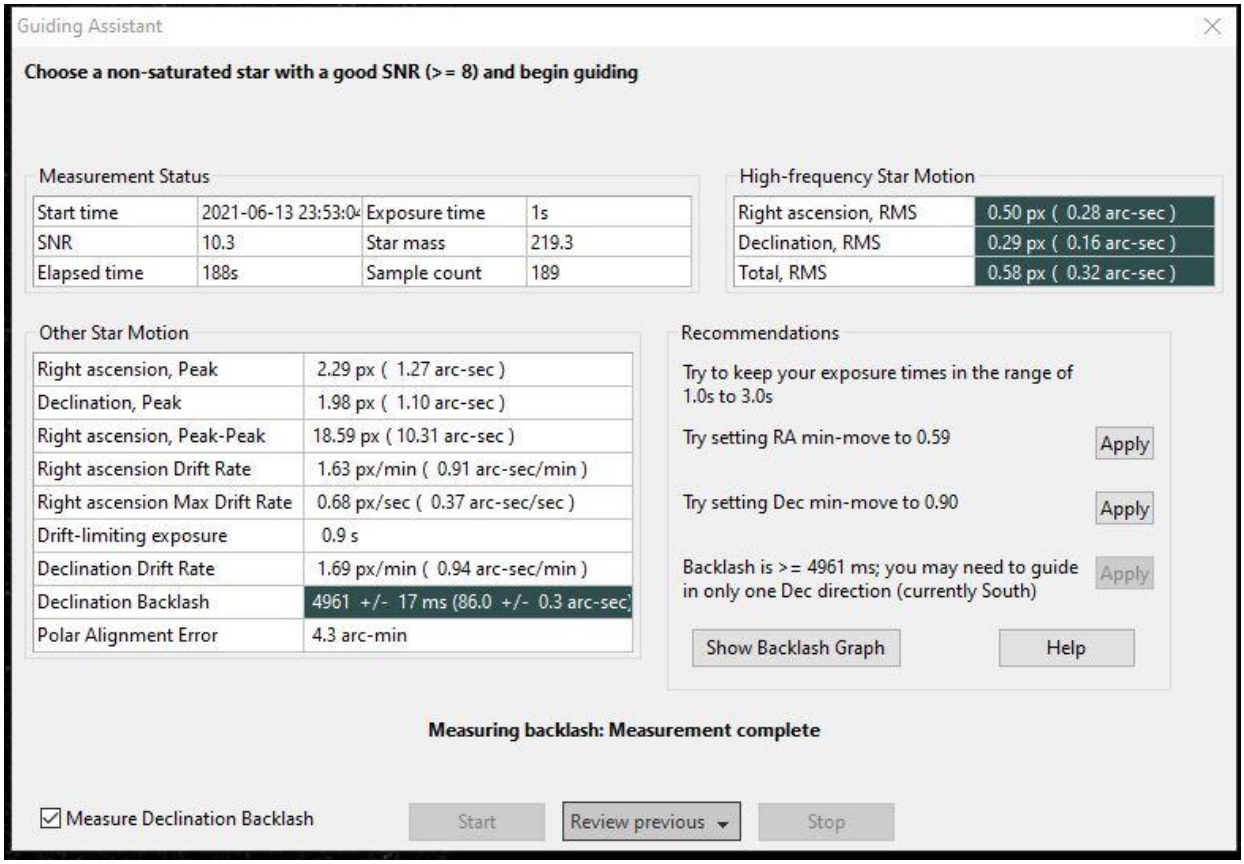


Figure 5 - Run 1 PHD2 guide assistant results

- A huge Dec backlash!
- A RA drift that is limiting guide exposures to 0.9s;
- Periodic error (RA peak to peak) is reported as a low (for an EQ6) 10.31 arc-secs but this is probably dubious as the assistant was only run for 188 secs.
- Pole alignment error of 4.3 arc-min which needs to be improved.

5 Imaging Test Run 2

Before performing another imaging run the following Activities were performed:

- Collimated scope; see my document on collimation on my website www.astroworkbench.co.uk;
- Mechanical backlash adjustment on mount RA and Dec. Procedure very well documented by Astro Baby at https://www.astro-baby.com/EQ6%20rebuild%20guide/EQ6%20worm%20alignment.htm;
- PHD2 used with ASI178MM on C11 at f10, FL=2790.
- ASI178MM pixel size = 2.4, run at bin 2. Guide star was Dec + 18. EQMOD pulse guide for RA and dec both set to 0.9x;
- Guide run for about 35 mins as shown below.

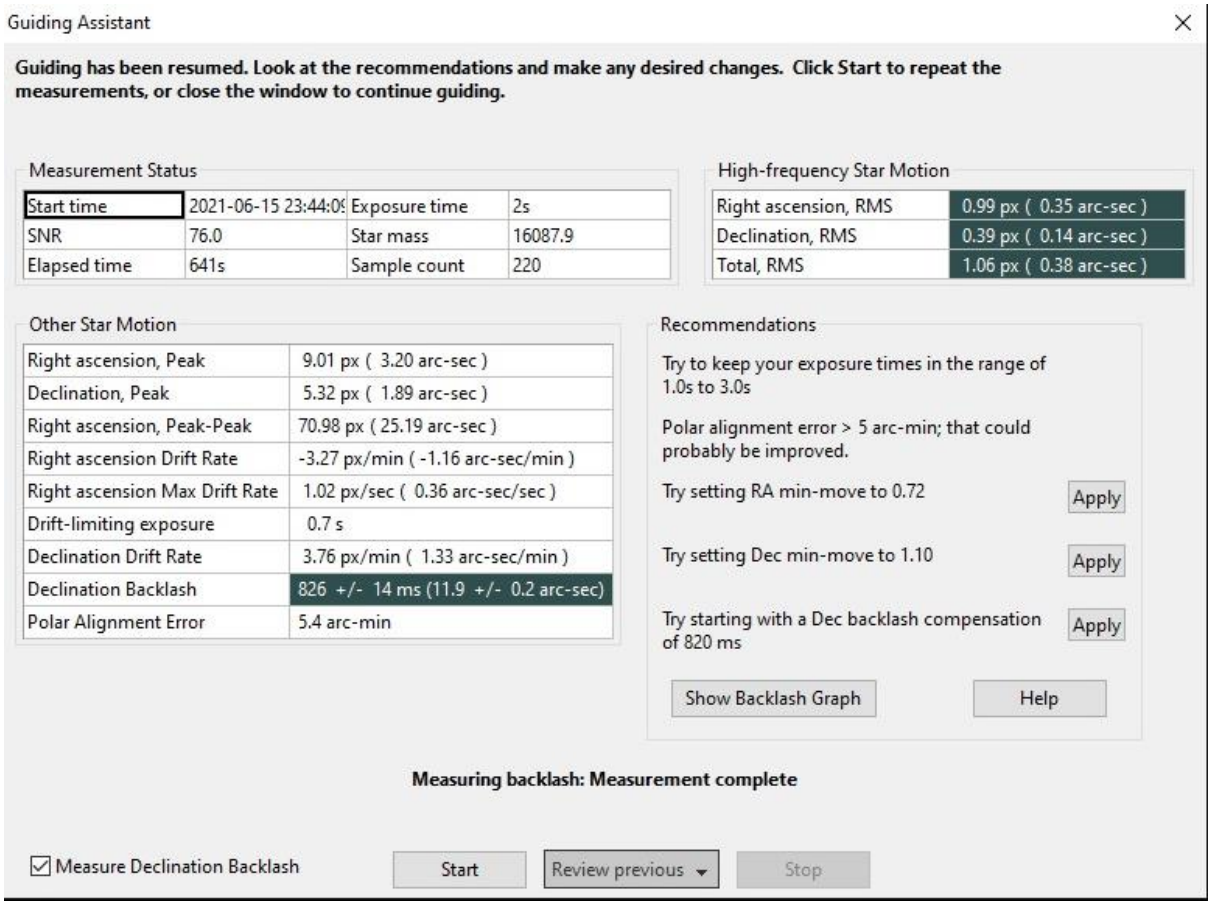


Figure 6 - Run 2 PHD2 guide assistant results

- Dec backlash much better (mechanical backlash fix on the mount obviously helped);
- RA periodic error around 25 arc secs, about normal for an EQ6;
- PHD2 guiding Limiting exposure time still < 1 second which is not good enough;
- Polar alignment error about 5 arc mins – needs improving;
- Tracking hasn't really improved, still jumpy 3 arc secs peak.

6 Imaging Test Run 3

Before performing another imaging run the following Activities were performed:

- Re-level the pier and mounting plate. This is shown in the figures below.

Figure 7 - Pier and mounting plate

Pier with mounting plate for EQ6.

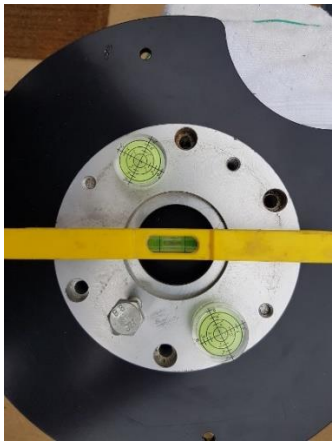


Figure 8 - Mounting plate levelled

I used three spirit levels to ensure the plate is level.

Figure 9 - EQ6 on mounting plate

EQ6-Pro on the mounting plate.

Don’t rely on the small spirit level embedded in the mount, the one on my mount was a mile off, clearly not fitted properly by the manufacturer.

- Used the PHD2 drift align tool; after altitude and azimuth tweaking a polar alignment error of 0.18’ was reported as shown below.

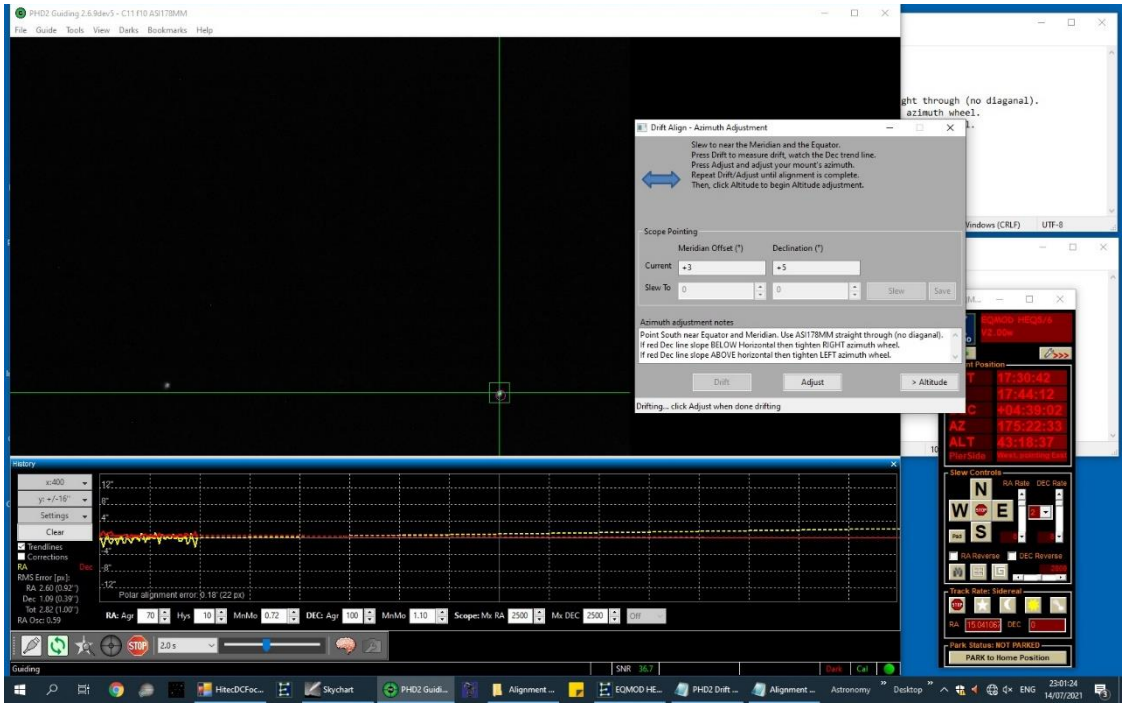


Figure 10 - Run 3 PHD2 drift align tool

- Ran the PHD2 guide assistant as shown below:

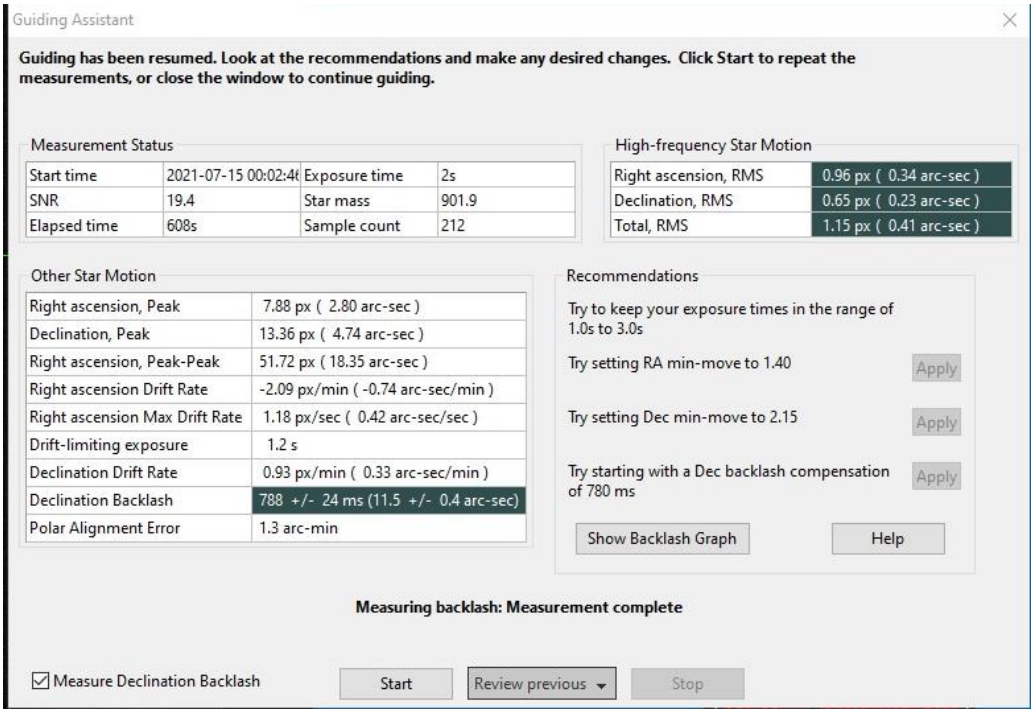


Figure 11 - Run 3 PHD2 guide assistant results

- RA periodic error of 18 arc secs is good for an older EQ6;
- PHD2 guiding Limiting exposure time is 1.2 which is just about acceptable;
- Polar alignment error about 1.3 which is acceptable;
- Tracking has improved, graph must less spikey and about +/- 1.5”;

7 Imaging Test Run 4

Before this imaging run I made no mechanical adjustment, but introduced a Celestron f6.3 focal reducer into the imaging setup. Due to the focal reducer to imaging chip distance being 115mm the actual working focal ratio is f6.

The PHD2 profile parameters (e.g. focal length of 1664mm) were adjusted for the new setup.

It was interesting to note that purely by reducing the working focal length from f10 to f6 PHD2 has bounced around some of the reported values that I would have expected to stay the same or improve, such as the drift limiting exposure and polar alignment are both reported as being worse, so it shows that these reported results can only be used as an approximation.

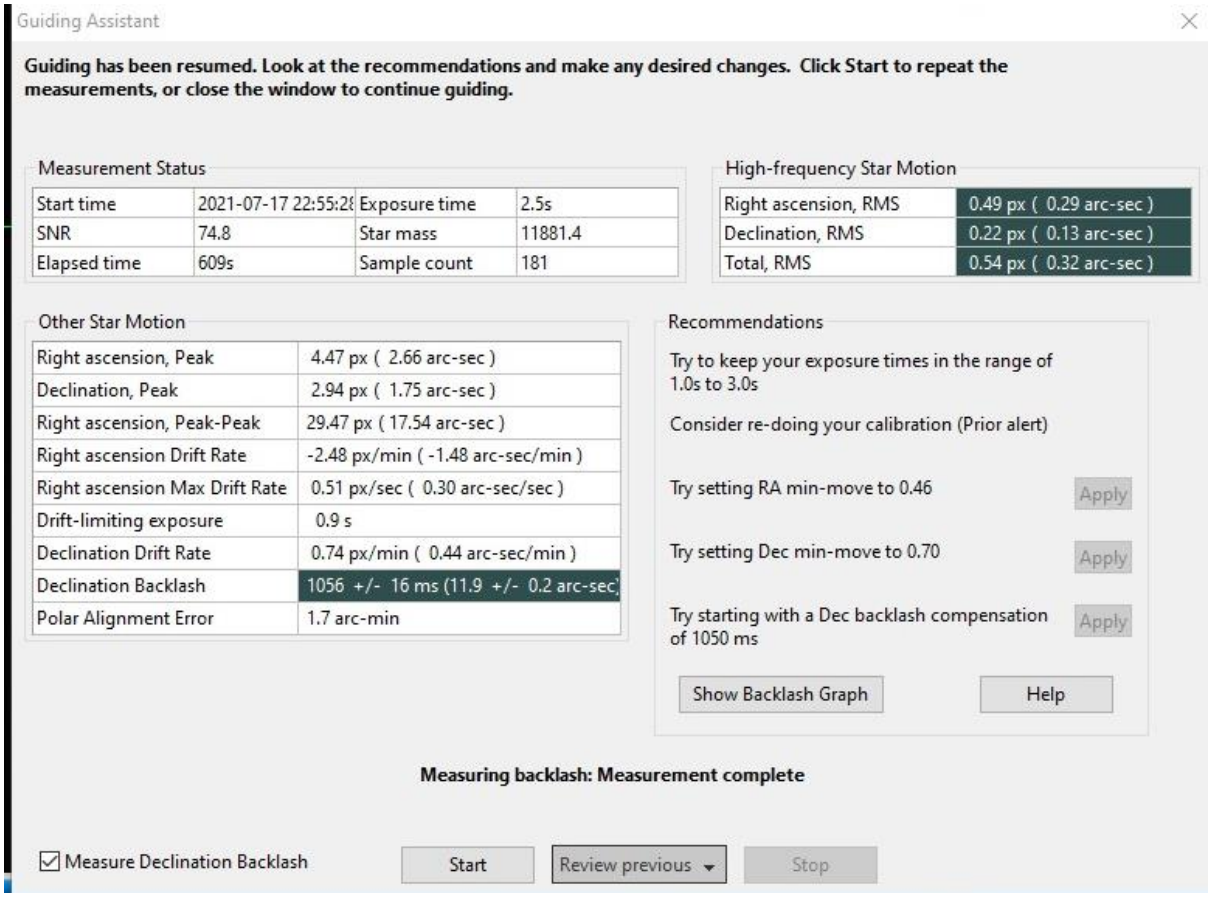


Figure 12 - Run 4 PHD2 guide assistant results

- RA periodic error of 18 arc secs is good for an older EQ6;
- PHD2 guiding Limiting exposure time of 0.9;;
- Polar alignment error about 1.7 which is acceptable;

8 Imaging Test Run 5

The only change before this imaging run was to train the EQMOD PEC, see the appendix for details.

The guide assistant results are shown below. The accumulation of all the tweaks and changes are now getting us somewhere and things are looking good.

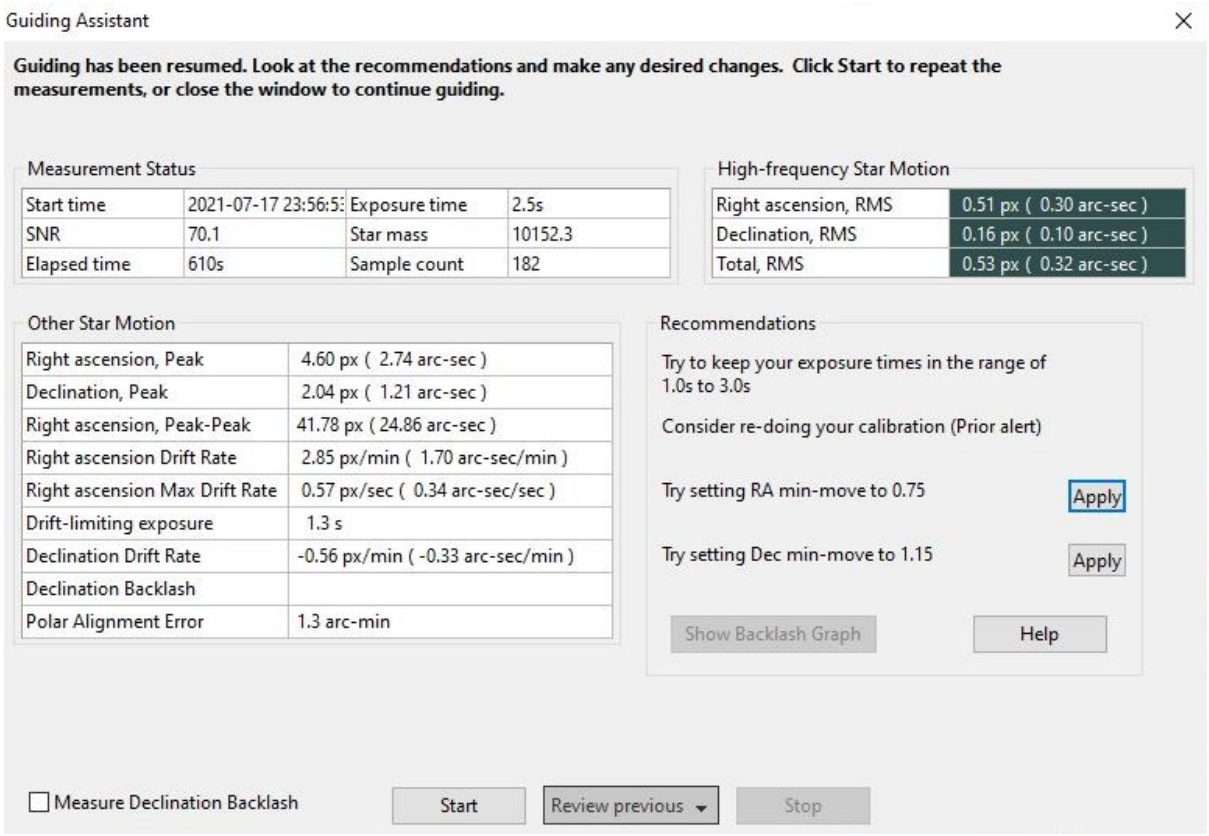


Figure 13 - Run 5 PHD2 guide assistant results

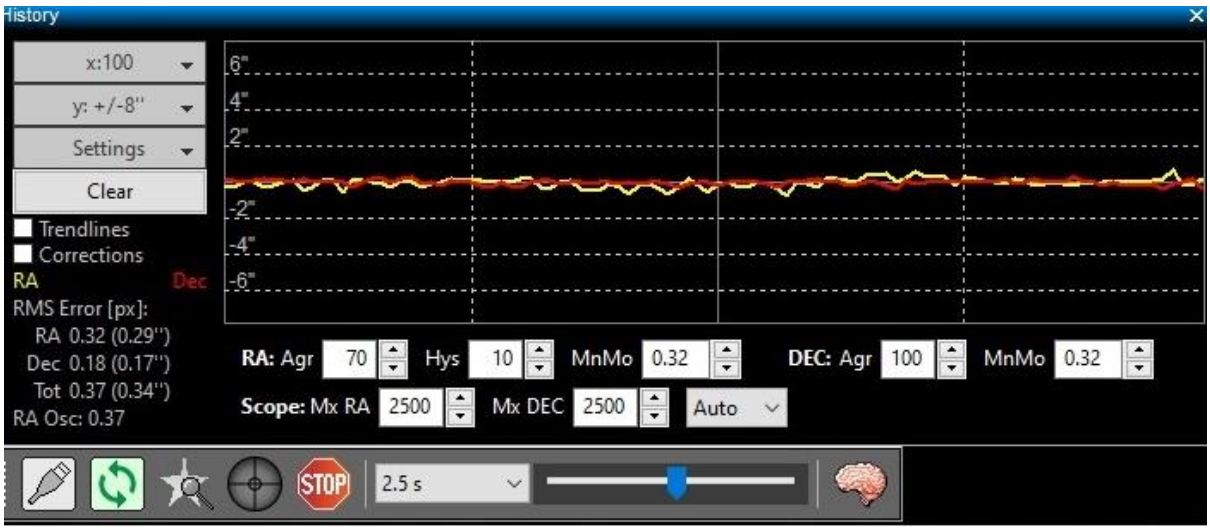


Figure 14 - Run 5 PHD2 guide graph

- RA periodic error of 25 arc secs is as expected for an older EQ6;
- PHD2 guiding Limiting exposure time of 1,3;;
- Polar alignment error about 1.3 which is acceptable;

- RA Oscillation of 0.37 (PHD2 documentation states it should be between 0.3 and 0.4);
- RA RMS of 0.29” which is acceptable for the imaging scale of 0.67 arc secs / pixel (see appendix for details);
- Dec RMS of 0.17” which is acceptable for the imaging scale of 0.67 arc secs / pixel;
- My eyeball tells me the guide graph is nice and flat with less than 1” jiggle;

9 Final Imaging Run 6 with results and conclusions

With no further tweaks, here is a test image of M27. It consists of ten 90s L images and five each of R,G,B using the setup as shown in *Figure 1 - Imaging and guide configuration for f6.3* at the start of this document

I have not cropped the image or enhanced the star tightness in the image below so you can judge the 'raw' result. The field of view is approximately half a degree and you can see that the stars in the center field of this test shot are reasonably tight (I confess, my focusing could have been a little bit better!) with no trails caused by poor guiding or polar alignment etc. The C11 coma is apparent at the edges which is to be expected as the Celestron f6.3 reducer is not a field flattener and the C11 does suffer a bit at the edges from coma (hence the extra cash Celestron charge for a C11 Edge HD to mitigate this).

Figure 15 - Test shot M27 result

Figure 16 - Central stars enlarged

Figure 17 - Edge stars enlarged – coma as expected

9.1 Conclusions

With regard to the PHD2 guide assistant's reported statistics, I am slightly surprised by the variation in the reported figures between runs (e.g. 10" to 25" RA periodic error) even when no changes have been made and guiding on the same star for the same length of time. However, they do undoubtable give a very good guide and most of the figures are stable and reflect changes made in an expected manner (e.g. the reported improvement in polar alignment after a polar drift alignment was performed).

After polar refinement, the PHD2 drift align tools reports a final polar align accuracy of well under 1', while the guide assistant reports between 1 – 1.7', which is sufficiently accurate poler alignment even at the worst case scenario of 1.7' for imaging.

EQMOD PEC has made an improvement as can visually be appreciated in the final flat guide graph shown above. It will never be the classic sinusoidal wave form for reasons detailed in the Appendix below.

All in all I would declare this process a success as the final test image run resulted in better imaging.

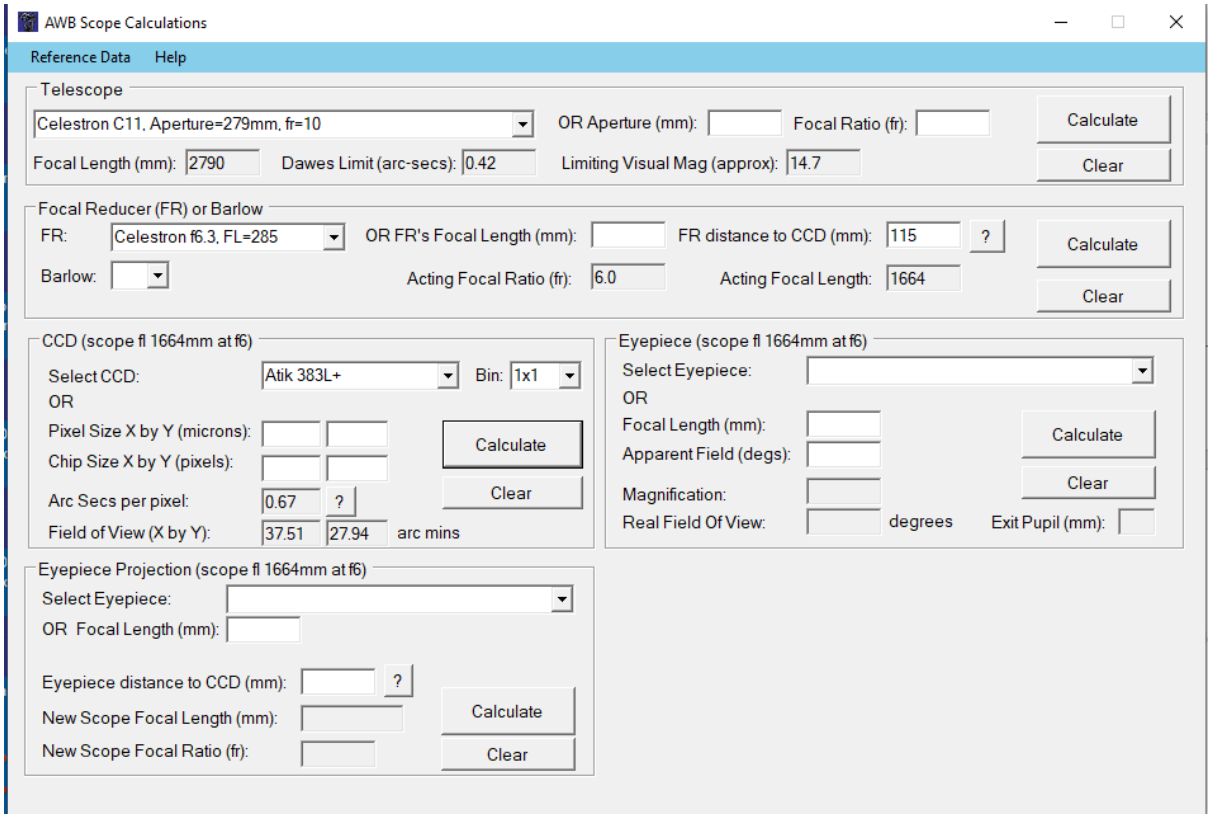
It must be kept in mind that the ultimate constraint on my setup is the engineering tolerances (or lack of them) on my old EQ6-Pro mount, but I reckon the following results are more than acceptable for this mount.

The principle final configuration tweaks and figures are as follows.

- Level the mount, balance and collimate scope;
- Use PHD2 drift polar align tool – resulted in a reported polar alignment between 1' and 1.7';
- RA peak to peak is between 10" and 25" (more towards the 25" end would be my estimate);
- PHD2 guiding at f6 with a focal length of 1664mm via Celestron C11, Celestron OAG and Celestron f6.3 focal reducer. It is working at f6 rather than f6.3 because the Celestron f6.3 focal reducer to imaging chip distance is 115mm in my setup;
- Atik 383L+ working at 0.67 arc secs / pixel at bin 1 (slight oversampling);
- Atik 383L+ FOV approximately 37' by 28';
- EQMOD pulse guide for RA and Dec both set to 0.7x;
- PHD2 RA oscillation for the test image was 0.37 which is acceptable (PHD2 documentation states that ideal is 0.3 to 0.4);
- PHD2 RMS RA figure for the test image was 0.29" which is acceptable when imaging at 0.67 arc secs / pixel;
- PHD2 RMS Dec figure for the test image was 0.17" which is acceptable when imaging at 0.67 arc secs / pixel;
- PHD2 guide exposures of 2.5 seconds;
- My eyeball tells me that there are no star trailing in images as you would expect with the PHD2 stats above.

10 Appendix A – Setup Calculations

The scope calculations for the setup described in this document are shown below. My Windows application shown below is free and downloadable from my website www.astroworkbench.co.uk.



11 Appendix B – Capturing EQMOD PEC

11.1 RA Periodic Error

My mount is one of the older EQ6 Pro mounts without a belt drive and the measured RA peak to peak error of over 20 arc seconds is fairly typical that other owners of this model report.

It's worth noting that RA periodic errors are not just caused by an RA worm wheel meshing to the RA ring gear as it is often described, but are also caused by the electronics, the RA motor, an in the case of my EQ6 mount the RA motor's gear (12 teeth)mating to an intermediate driving gear (36 teeth) mating to the next gear (47 teeth) that drives the worm wheel that then engages onto the final RA ring gear (180 teeth). That's a train of electronics->motor->four gears and a worm! The engineering tolerances on all of these can contribute to the quirkiness of the RA graphs so the perception of a raw data peak to peak curve always being smooth and repeating that you often see in examples is not really true for all but the best of engineered mounts.

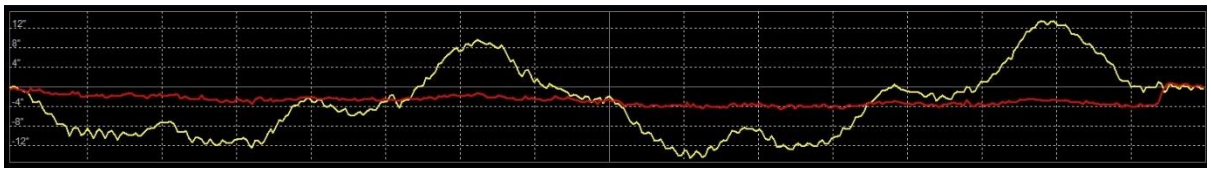
The RA graphs would, for the EQ6-Pro, therefore typically show a peak to peak corresponding to the 478 second cycle of the final 180 tooth RA ring gear with some interspersed 12, 36 and 47 gear cycles to mess things up.

For some mounts that feature superb engineering tolerances with virtually no RA error the use of PEC can be pretty much superfluous to your needs as it provides no clear advantage over allowing PHD2 to 'guide out' any such small RA variations. However, for a medium priced and engineered mount such as my EQ6, PEC can be worth it rather than just leaving PHD2 to try and guide out the EQ6 tolerances.

One conclusion that I have come to is that It is important to use the PEC feature provided by EQMOD and **not** the PEC (or PPEC) built into your mount. My reasoning for using EQMOD PEC as opposed to the EQ6 PEC is that if you would have two separate systems providing independent guide corrections and you may enter into an antagonistic tussle between the two, whereas if you use EQMOD to learn and apply PEC then it seems to work in unison with the EQMOD pulse guiding implementation.

It must be remembered that to re-use the EQMOD PEC results it is imperative that you always PARK and UNPARK via EQMOD at the end and beginning of your observing sessions. It is ok to move your mount manually by releasing the clutch as this will not rotate the RA worm and wheel positions. I have some doubts about the encoder accuracy and hence the PARK with my EQ6 and I have found that the accuracy of the PEC replay can therefore deteriorate over time as the RA worm and wheel's actual position may have wandered from its original PEC capture position.

As an example, the image below shows a typical "raw data" RA drift for my mount (from PHD2) and shows a 20" RA peak to peak error with the two main peaks corresponding to the 478 second cycle of the final 180 tooth RA ring gear with some repeating interspersed noise probably induced by the 12, 36 and 47 gear cycles.

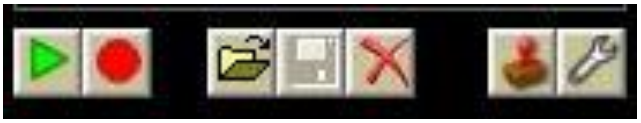


11.2 Capture EQMOD AutoPEC

To Train PEC using EQMOD's AutoPEC facility use the PEC screen as shown below which is accessible by clicking the  button.

Figure 18 – Initial EQMOD PEC Training

The button bar across the middle is the business end of this screen and is explained below. The graph at the top of the screen will show the current PEC curve once captured and the capture corrections will be shown in the graph at the bottom of the screen



The buttons are (left to right):

- Play / Pause current PEC corrections
- Start / Stop PEC capture
- Load a previously captured and saved PEC file (that contains corrections)
- Save a PEC file
- Unload currently active PEC file
- Set time stamp
- Setup

The easiest way to capture and use PEC is to use the EQMOD AutoPEC ability as follows: -

- Ensure that you have completed the polar alignment as described previously;
- Ensure that the *Enable Mount Guide Output* checkbox in the PHD2 advanced options tab is checked on;
- Ensure that PHD2 and EQMOD are configured and connected to use Pulse guiding as described previously;
- Ensure that PHD2 is guiding your scope;
- Click the *Setup* button on the button bar as shown above and ensure that on the subsequent screen the *Auto Apply PEC* checkbox is ticked and at least the default 5 *capture cycles* is specified (numerous cycles are required for EQMOD to average out the results);
- Click the *Start PEC Capture* button on the button bar as shown above;
- Five cycles will take about 40 minutes on my EQ6 Pro mount;
- Once completed, EQMOD will automatically use the captured PEC and will display 'Siderial+PEC' as the guide mode being used;
- Remember to **always PARK and switch off the mount** once you have completed your observation session otherwise the PEC results will not be applicable next time you use the scope (you can disengage the RA clutch and manually move the RA axis after its PARKED and switched off if you desire as this will not change the RA wheel index position).

12 Further Information

Please visit my website www.astroworkbench.co.uk for further documents and articles.

Thanks.

Keith.