# Autoguiding – Advanced Techniques

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## *Introduction*

It is time we take a systematic approach at this very important topic of astrophotography to get the most out of our expensive gear – mount, guide scope, guide camera, main camera.

The aim of this document is to help understanding the process of autoguiding and to get the best result possible with your gear. It is intended for both beginners and experts.

Autoguiding is an attempt to track the sky with smaller error than the pixel scale (smallest visible error) of our imaging (main) camera. While trying to correct mount errors we want to disregard seeing blur (except with active optics using high frequency).

Let's start by creating a list of the players of the game.

Guide star – its position on the guide chip is measured by the guide software at regular intervals, normally with a few seconds (1-5) of integration. The measured so called "guide error" is the result of mount tracking errors (refraction and mechanical errors) and seeing blur.

Mount – it tracks the sky as precisely as its polar alignment, software and mechanics allow.

Guide camera – it takes images of the guide star and sends them to the guide software for analysis.

Guide scope (separate) – images the guide star for the guide chip. In case of off axis guiding or dual chip camera we have no guide scope.

Guide software – this is the brain of the system, interprets the guide chip data and sends guide commands to the mount.

Main telescope – don't blame everything on the guider, the main telescope is half of the story

## *The process of guiding*

It all starts with taking an integration of the guide star. Let this be 2 sec.
When finished, the image is downloaded and analyzed by the software, the centroid position is calculated (to $1/100^{th}$ of a pixel normally). Let this be 0.2 sec.
A guide command is sent to the controller which responds with small delay, say 0.05 sec.
Now the mount/telescope accelerate and occupy the corrected position in , say, 0.2 sec (the correction was 0.15 sec).

The cycle has ended and after a small delay (if set) to let the mount settle a new exposure is started. The cycle time in this case is 2.45 sec. If we consider the midpoint of the exposure, the correction has been finished 1.45 sec after the position of the guide star was taken.
This example makes it evident that autoguiding always has some uncertainty in it. The worse the seeing and the more erratic tracking is, the worse the situation is.
We can conclude that seeing and mount performance are important limiting factors of guiding precision.

In theory making the guide cycle shorter and shorter the result gets better and better. The problem is that a 40 kg of equipment cannot be moved several times a second. Active optics has been introduced to overcome this problem but there you need a bright guide star to be fast enough. Ooops, life is difficult!

## *Choosing the right setup*

Also we cannot change seeing and our mount has some error we cannot remove, we do have important choices.

## Guide star

The guide star should not saturate on the guide chip. It should be bright enough to give a reliable S/N ratio. The ADU level should be between 30 – 90% of the max value (255 for 8bit, 4095 for 12 bit). Beware of close double stars!

The guide star will ideally be close to the imaging target because dec drift and refraction can be different, not to mention field rotation if polar alignment is off (and you are working near the Pole).

## Guide scope

Using a guide scope with a decent guide camera seldom leaves you without a guide star. This is useful but raises a lot of mechanical problems. Use this if you understand mechanics and do not want to take subexposures longer than 5-20 min.
If your main telescope has shaky mechanics and optics that can move a little, use an off axis guider or a dual chip camera. For subexposures over 20-30 minutes this is the only solution with most telescopes.

Remember that an off axis guider system can suffer from optical aberrations (coma, astigmatism, etc) if the optics are not corrected for the rays that reach the guider. Stars plagued by coma give less precise centroid position values.

If you use a separate guide scope pay attention to the following:

The aperture of the guide scope should not be above 80mm to minimize bad seeing effects and weight. The focal length has a lower limit based on considerations of resolution.

Let's suppose that you want the guide software to be able to detect $1/10^{th}$ of a pixel error in your imaging camera and your software calculates the centroid position to $1/100^{th}$ of a pixel.

Based on these criteria we can calculate the minimum focal length of your guide scope.

These are the numbers you need: a=imaging camera pixel size
b=guide camera pixel size (both in microns)

Guide scope focal length (FL) = main telescope FL x b/10a

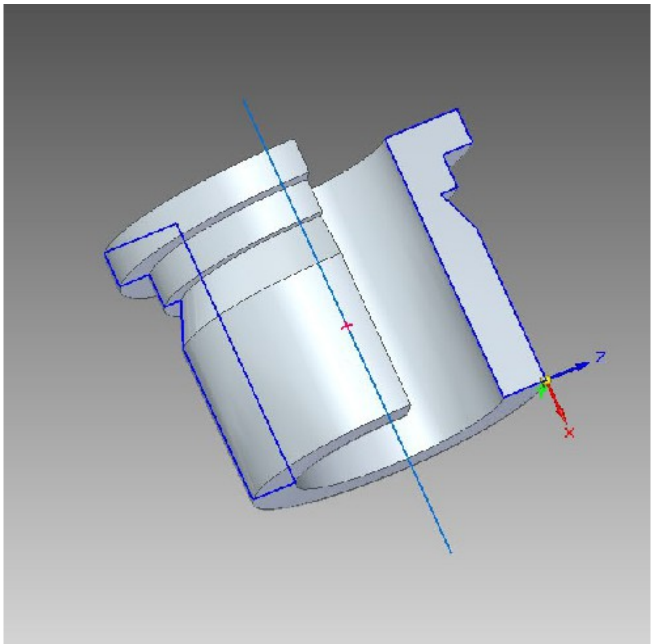
Do not use a FL much longer than necessary because it will mean a heavier guide scope and more flexture. The FL doubles if the guide camera is used in 2x2 binning.

The guide scope will preferably be a refractor (less opical parts, more stable mechanically) and if possible at least semiapochromatic. You will need an IR cut filter to have tight stars. A red filter with IR cut is giving very tight stars and less seeing blur. With the red filter an achromat is also ok.

All mechanical parts of the guide scope and its support must be rigid and professional. The same is valid for off axis guiders and the main telescope. The longer subexposures you wish to take the more strict these requirements will become.

Take good care focusing the guide scope. The position of an ill focussed star is measured less precisely.

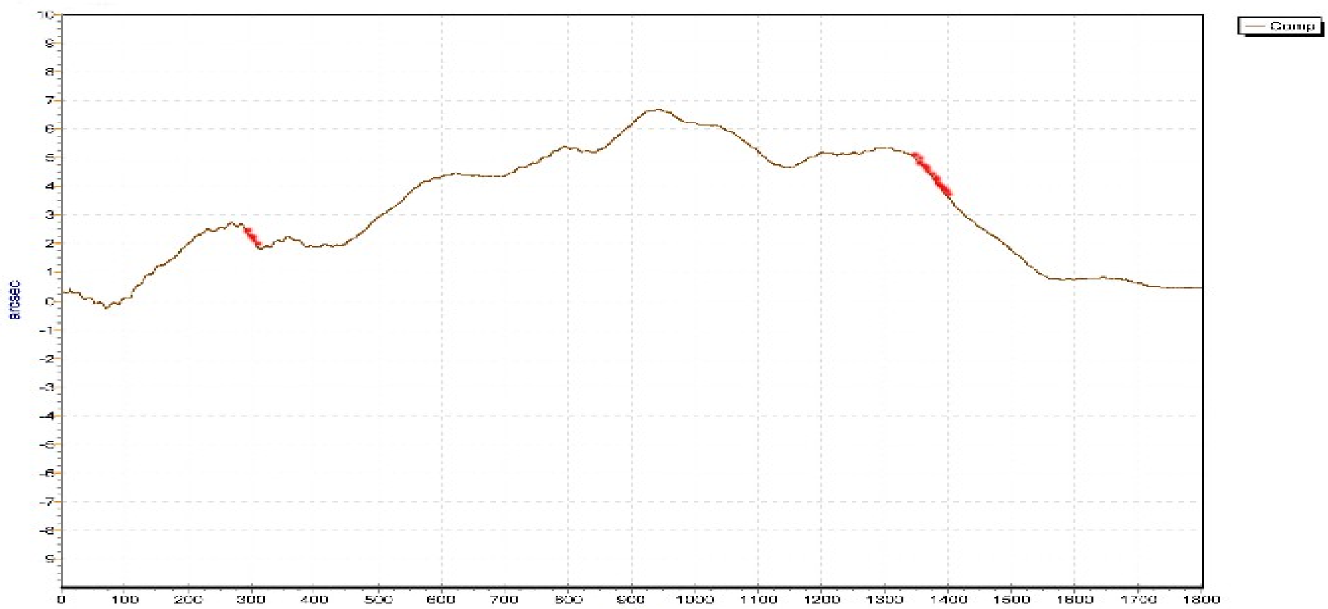
*On the right you see an adapter with a tapered groove. On your guide scope and main telescope you should use threaded connections or adapters like this, fixed with 2 or 3 thumbscrews laterally.*



## Mount

It is a good idea to learn how your mount tracks. It is not enough to know the PE of a mount. You will need the guide error graph with points every 1-2 seconds to have all the info you need. You will want to know the longest time (in seconds) your mount can track unguided with the precision you need for your imaging (1” for example). Take a close look at the graph and look for the steepest part in the curve. Now find out in how many seconds the mount takes to reach the error of 1” (or your value)? If it is 3 seconds (example), you will not use guide integrations longer than this, otherwise your images might smear.

*In the example below critical parts of the PE curve has been marked with red.*




It is obvious that using PEC will let you use longer guide integrations, which in turn will decrease your problems with bad seeing. Some controllers do not support PEC *and* guiding but most do, so use it!

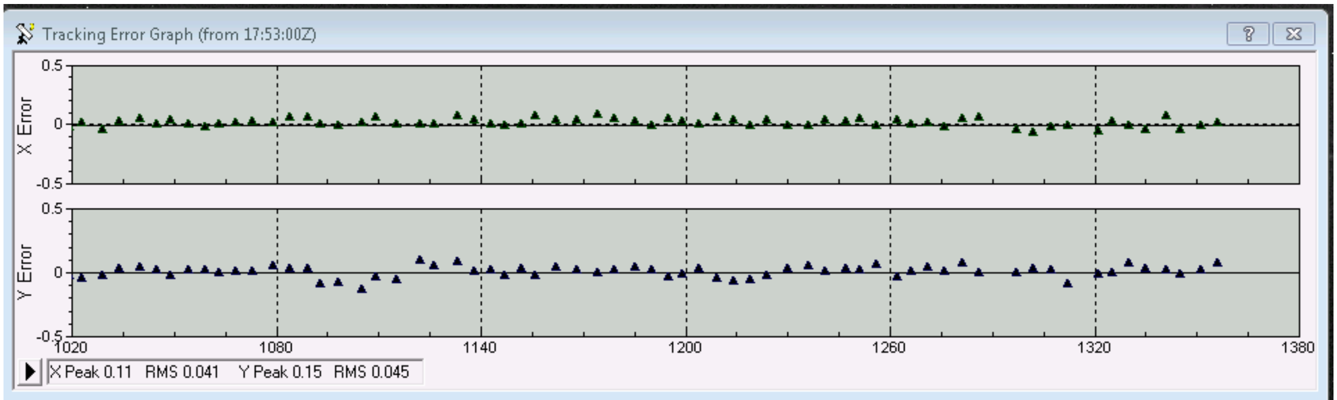
If there is backlash in your mount at the telescope end, unbalance it slightly. In RA unbalance so that it tends eastward. In DEC the direction is indifferent. Backlash in the gearboxes can be minimized if the controller or the guide software allows dec backlash compensation. Unfortunately backlash in a gearbox is not a constant value, so it is normally impossible to define a value that will always work. In this case calibrate it for each new object.

If your controller allows setting a stop current make sure it is not much lower than the current used for tracking. Otherwise the DEC motor may jump (steppers only) when it has to move the telescope after a few seconds of inactivity.

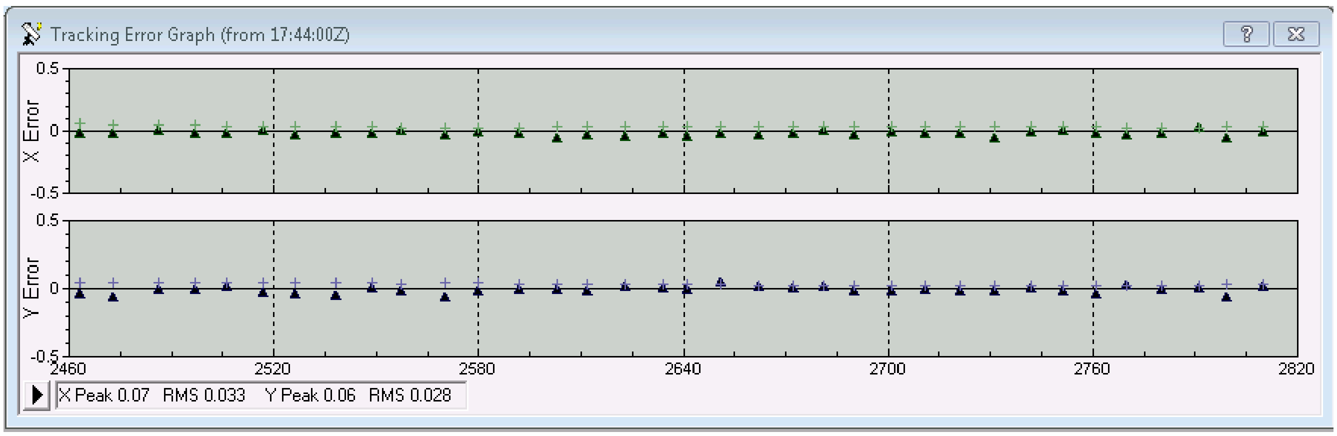
If you encounter strange, sudden jumps in DEC a possible source are the RA bearings of your mount. There is normally little you can do about it other than replacing them.

The way you connect the mount to the computer can have an effect on guiding precision also. Compare the results (guide statistics) on the same night and object with an autoguider cable connected to the mount's AG port and with selecting “Telescope” as connection (this will send the commands to the mount on the serial/USB line. Using an autoguider cable means having one more player in the game, the CCD camera relays, which is not always desirable. *Below is an example. The difference is statistics is evident. The mount used is a Gemini G53F with Pulsar2.*

*Guiding via Camera Relays*




*And via "Telescope"*




Many controllers offer 3 star alignment that corrects goto-s and even tracking speed if polar alignment is off. This is cool but they will not correct field rotation which can be very frustrating near the Pole. If you are serious about your work you need good polar alignment.

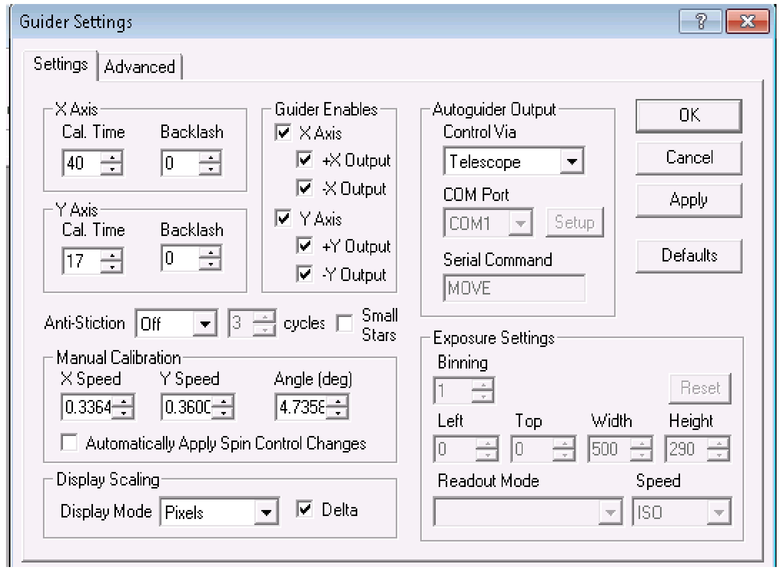
## Software

Incorrect settings can deteriorate your guiding performance.

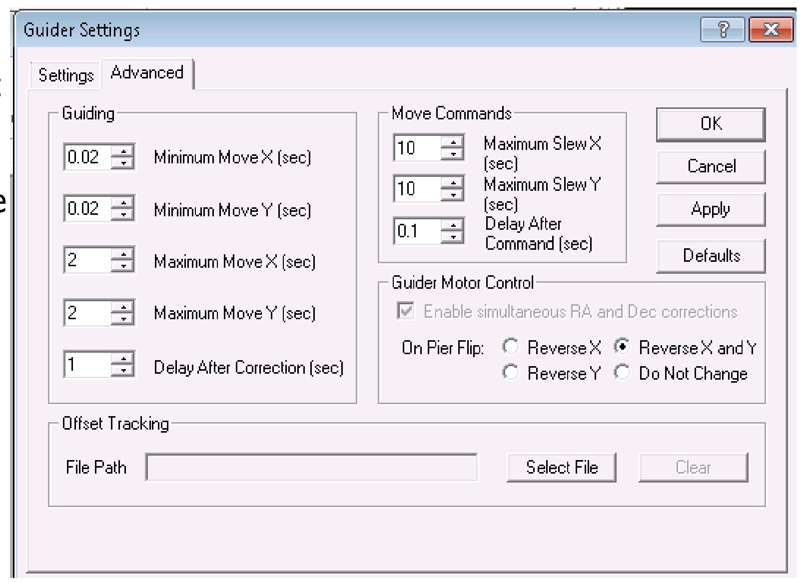
Start by selecting the guide speed in your controller. The more guide precision you need the smaller guide speed you should choose. This is because the smallest possible correction (in time) is limited by your controllers response rate and mount inertia. For an image scale of 1-2 arc sec I use 10% (of sid speed) guide speed. This means that a correction of 0.1 sec is roughly 0.1 arc second.
When imaging with a telephoto lens you will not need such small corrections and a higher guide speed will work better.

As stated above, your guide star must not be saturated. Saturation makes centroid detection difficult and imprecise.

The giude integration must be chosen according to mount performance as explained above, guide star brightness (no saturation but good S/N ratio) and seeing quality (longer exposures average out seeing blur better).




Calibration is normally the next step. To calibrate the mount we need to move it for several seconds, otherwise the result will be very imprecise. On the other hand, during guiding we never move the telescope for several seconds, just a fraction of a second. The average speed measured during calibration will be higher than the speed we would find moving the telescope for 0,1 sec, for example. This is because the mount has to accelerate, as all bodies with inertia have to (your car for example) . I recommend decreasing the calibrated speed by 10% and check the guide performance. If there is frequent overcorrection (consecutive errors are on the opposing sides of the line, after + there is -) decrease agressiveness.




If your controller allows simultaneous correction in RA and DEC, enable it, it saves you valuable time.

The minimum correction time must be set considering your imaging error margin and your mount's capabilities. Experimenting is useful here but the lowest value you enter the higher the chance of a less than perfect result. I would not enter less than 0.02 sec but if you have chosen the correct guide speed this parameter has a small effect on the result.

The maximum correction time limit serves to save you from correcting occasionally on a hot point of the guide chip.*At above right is an example of guide settings in Maxim DL5 for a German Equatorial mount.*

## Guide camera

The important parameters of the guide camera are:

Sensitivity. The more sensitive the fainter the guide stars can be.
Noise. A noisy chip will corrupt centroid detection.
Size. Larger chip detects more possible guide stars.

Download time. The shorter the better.
Weight and size: a lighter camera creates less flexture, a smaller fits better into off axis heads.

In theory guide algorithms can work with badly inclined chips but it definitely helps to have the chip oriented parallel to RA and DEC in the sky. At least it helps you see where your guide problems come from, may you have any.

A very important characteristic of a guide camera is noise and chip quality. Bad pixels and high readout noise will hamper centroid detection precision in a random manner. Using the camera in 2x2 binning reduces noise but the minimum focal length of the guide scope will double in this case.

## *Troubleshooting*

If you always have pinpoint stars in your images you are probably not reading this paper at all. If this is not the case I will help you get your stars perfectly round.

It is not only guiding that can cause problems.  Stars can have distorted star profiles for several reasons.

The importance of tracking or guiding an exposure is diminishing towards the celestial Pole. For this reason tests concerning guiding or tracking performance are done around Dec=0 and near the Meridian. Tests concerning errors not related to tracking or guiding (like collimation, tilt) are done better near the Pole where tracking errors will show less in short exposures.

Optical problems – poor collimation, defective or stressed optics, loose parts in the OTA can all produce problems. Sometimes filters can be defective and distort the image or the chip is tilted in the camera.  A flexing or misaligned focusser also falls in this category because it produces similar effects.

Mechanical problems – flexture in the parts holding the guidescope or off axis camera, or the main camera.

Tracking problems – all the rest that I have been talking about so far.

This seems complex but there are simple ways of separating these errors. The key to success is a systematic approach. Don't trust any part of your setup blindly, test them all!

A very easy case is when the stars have different shapes in different corners of the image. This is mostly due to collimation problems and tilt of the camera or chip.

The fact is that optical errors are normally always present, even in the shortest exposures, while mechanical errors tend to accumulate with time. Guide errors can be tricky to pinpoint because they may be different night by night or by mount position, just as mechanical ones.

First we will exclude optical errors by taking 10 short unguided exposures, say 5 seconds each (find a field with bright enough stars for this). If there are perfect stars in any of the 10 exposures you have no optical problems, but guiding or mechanical ones.

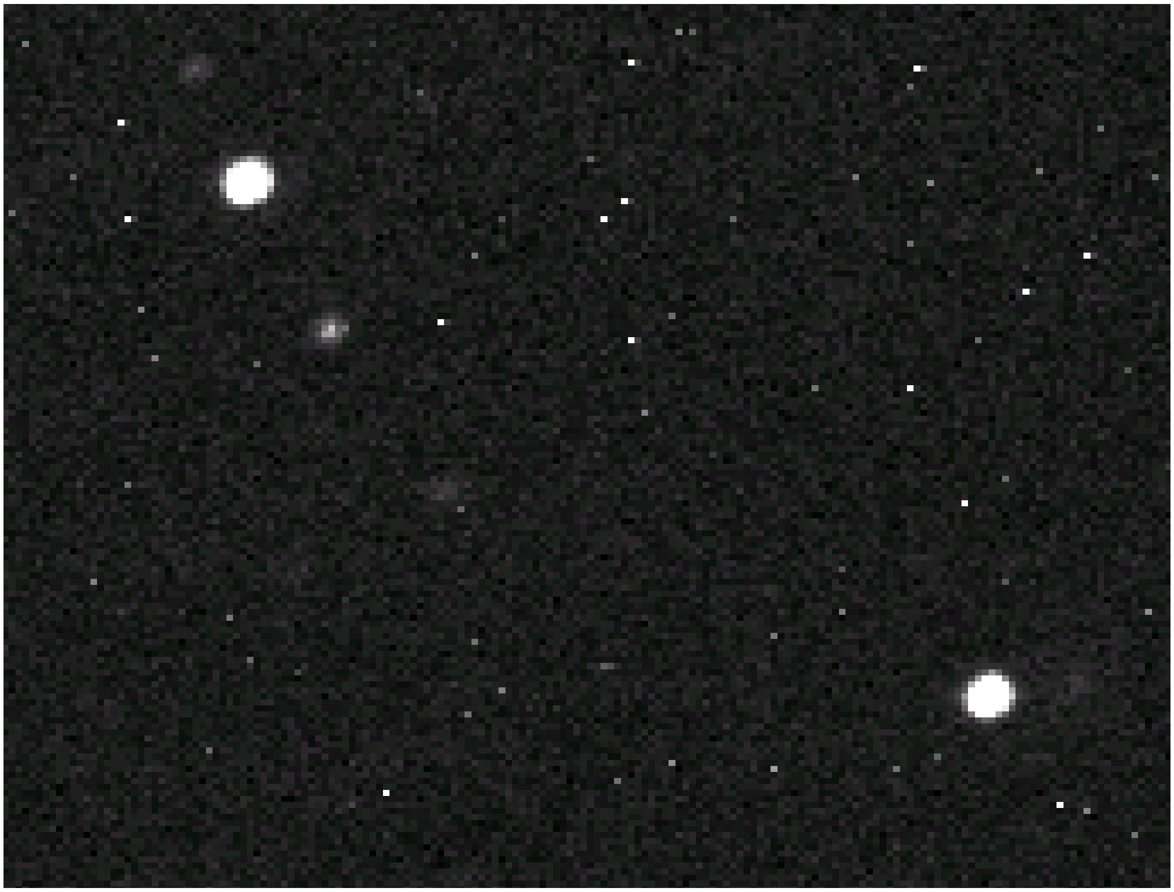
Separating guide errors from mechanical ones is a bit tricky but not impossible.

Take a series of guided exposures with increasing integration times,  60, 120, 240, and 600 seconds (or your longest desired sub). Take 2 of each. Examine all the images carefully. Ideally, the shorter ones should be ok and the longer the exposure the more trailed the stars are. This is tipycal of flexture. Unfortunately the actual position of the telescope can influence the result so you may need to repeat the test in several sky locations until the results are unambiguous. If you have flexture you have to carefully check each part of the guide scope and its support, plus the main camera support, including the focusser.

Another easy way of diagnosing flexture is to look at a series of subexposures from the same night and check for systematic small drift in star positions among consecutive images. If there is some, it is most likely flexture of the guide telescope or the main telescope (or both).

The direction of the error (star elongation) is also an important information. If it is not exactly in RA or DEC you will suspect flexture. If it is exactly E-W or N-S you have probably guide problems BUT there is a small chance that flexture in that particular case falls in one of the main directions so be careful!

*Below is a crop from a 30 min frame at 1,6”/pix, with sign of flexture. RA is horizontal.*



Remember that the only setup 100% free of flexture problems is the dual chip camera (naturally that has other severe drawbacks). An off axis head can also have flexture where the camera is attached to the head or at other interfaces. Filter wheels can also introduce flexture if loaded with a heavy camera. I am not talking of internal wheels of course.

Should all the exposures (short guided and long guided) show trailed stars (even if not to the same extent) and you have passed the unguided test, most likely you have problems with guiding and you need to study the first part of this paper carefully.

If your test shows optical problems you will want to start solving them at the camera end, by rotating one part of the system at a time (if possible). Rotate the camera first and see if the distortion rotates on your monitor. If it does, the error is not with the camera. Next, rotate the focusser (but keep the camera orientation fixed) and check the result. If the distortion has rotated your focusser is probably misaligned.

Finally a few words on another source of errors – external, that is outside your observatory or gear. The longer subs you take the higher the chances are that something will disturb the guider occasionally. These factors can be many. In my experience I have seen the following:

spontaneous cloud condensation, occultation by a jet, cosmic rays.

*In the image at above right (30 min sub) brighter starts have a "nose". Something has disturbed the guider in RA for a few seconds, leaving a sign on brighter stars only.*

Summing up, here are the questions you will want to ask when hunting down errors:

*Is the error present uniformly on all parts of the chip?* YES/NO
YES: guide problem, flexture
NO: collimation, tilt (of CCD chip)

*Is the error present on a short unguided exposure?* YES/NO
YES: collimation, tilt
NO: guide problem, flexture

*What is the minimum length of guided exposures producing the error?* Shorter/longer than 30 sec
SHORTER: guide problem, collimation, tilt
LONGER: flexture

*What direction on the chip/sky is the error falling in?* Main direction/arbitrary

MAIN: guide problem
ARBITRARY: flexture, collimation, tilt

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