



does not use brightness or sharpness as a measure of focus, instead uses a unique measure of image size called “half flux radius” (the radius of the circle containing half the image flux). It turns out that the image size as measured by the hfr changes linearly (constant slope) with distance away from focus even for doughnut shaped images from an S-C telescope. A plot of hfr versus focus position is a V-shaped curve centered on the current best focus position. The slope of the V-curve will depend on the optical and mechanical characteristics of the system, while the left-right position of the V-curve will shift with temperature or other factors that affect focus. Once the V-curve is measured, in principle one could measure the hfr of a single image and use the slope from the V-curve to compute and move to the focus position. In practice, HFR Focus takes several images in an iterative process to determine best focus. Because the hfr can be measured accurately very far from best focus, using HFR Focus does not require an accurate starting position, and involves only a limited number of images from which the proper focus position is calculated and moved.

The two program designs fundamentally differ. In essence, @Focus takes a new focus curve each time the user wants to focus the telescope. On the other hand, HFR focus uses a training process that initially takes a more detailed and accurate version of the focus curve over a much broader range, then uses those data in future focusing to do faster focusing. This difference ultimately derives from how out-of-focus is measured, i.e., brightness or sharpness in @Focus versus half flux radius in HFR Focus.

### **HFR versus @Focus**

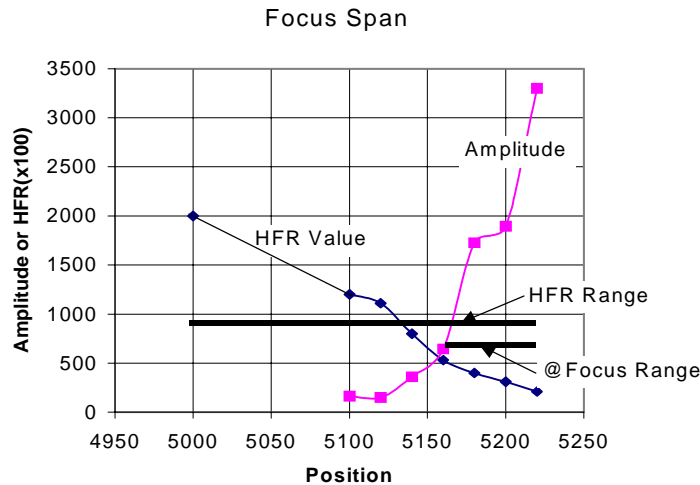
The following are observations and conclusions about the two programs. We will refer to two focusing situations as “ideal” meaning a bright star and fairly well known focus position, and “nonideal” meaning poor signal level and/or not well-known focus position.

**Accuracy and Range of Focus.** Both programs can deliver accurate focusing. HFR will operate more effectively under adverse conditions of low signal level and out of focus distance, i.e., non-ideal conditions.

- @Focus tends to require in focus peak readings of around 10,000 counts (which is a substantial fraction of full scale) in order to produce at least 1000 counts in the starting out of focus image (@Focus does not like lower brightness values).
- HFR can accommodate out of focus signals as low as 150 counts or lower.
- In a typical setup (R&P on the f/12), @Focus required that a focus cycle begin within about 150 position counts of focus (for our setup), while HFR would easily operate starting 300 or more position counts from focus.
- If focus has shifted very far (e.g., as a result of temperature change) or if you change star image brightness, in @Focus you may have to determine a new starting position for focusing while in HFR Focus you will always begin from the same preset starting point

These characteristics (tolerance of variable brightness and out of focus distance) make HFR much easier to use in non-ideal conditions. In fact, HFR can focus starting with an out-of-focus image that is as large as 50% of the entire field of view in an ST7. This is especially true for images from scopes with central obstructions: the HFR focus measure works much better in dealing with “doughnuts” than does the @Focus maximum or sharpness measures. On the other hand, if a reasonably good brightness star is available, and one is normally trimming focus in a standard routine, either program will focus successfully.

Below is a graph that shows the amplitude of the star image versus focuser position. We also show on the graph the approximate range of focus for @Focus (within which focus is quick for the star used), and the approximate range of focus for HFR Focus. The amplitude is the maximum value of a gaussian curve fitted to the star image by MaximDL. At the point of maximum amplitude, the maximum pixel value happened to be about 5000 counts (it could easily vary from 3-6000 as a result of statistical variation plus very slight position shifts that cause different portions of the tight image to fall on nearby pixels). Though not shown here, the amplitude curve, of course, continues over the top and down the “far” side. The graph also includes the measure of hfr at each focuser position: this is essentially the left half of the V-curve derived from training the system. The hfr values are multiplied by 100, so that at position 5000 the hfr of the out of focus star was about 20. The Maxim amplitude at that point was in the noise although HFR Focus could still measure the image. @Focus would have been unable to read the image.



Although on successive images HFR focus tended to focus to a narrower focuser position range than @Focus, both repeatedly achieved a focused image whose FWHM varied by only about 10-20% (corresponding to a focuser position range of about 18 counts, a very small amount for this setup). This degree of focus precision is probably better than most users do “manually” even when using RoboFocus, and is far better than most users can achieve turning knobs with their fingers.

**Speed of Focusing.** Speed of focusing under ideal conditions is about the same for the two programs—about 30 seconds for HFR Focus and about 45-60 seconds for @Focus. However, in non-ideal conditions or with a poor starting position, @Focus can take many minutes to find focus, and may not find it at all or find an incorrect focus. In non-ideal conditions, HFR will still normally get to focus in its regular 30 seconds. If conditions are so bad that it is not possible, HFR will normally announce failure within 15 seconds or so as it fails to acquire a target star. Neither program has a user settable limit on movement.

**Focus Star Selection.** Operation in cluttered star fields is much easier with @Focus. If there are several “bright” stars in a given field, in @Focus you normally select one by drawing a subfield around it. HFR, on the other hand, selects the target star only automatically. This works well with just one star present, but the current version of HFR Focus can be confused by other stars or extended bright objects. Both programs, of course, use subfields during autofocusing as a means of speeding up focusing operations. Incidentally, both programs keep a log of operations.

**Independent Focusing.** The two programs differ greatly in their provision for independent focusing. @Focus provides only the ability to step the focuser in preassigned “large” or “small” steps so moving to a particular focus position may be time consuming or difficult. This is made worse by a bug in the @Focus software which does not allow the user to disconnect @Focus from the RoboFocus COM port without closing CCDSoft totally. Thus, switching to the RoboFocus control program for movements or to change configuration is extremely awkward. HFR operation displays the RoboFocus control screen, so that movements or configuration changes are easy (the screen can be minimized if desired).

**Optical Setups.** Different optical setups are easier to handle in HFR focus. If you have separate setups (e.g., operate at f/12 vs f/36 using Barlows), you will have trained the system for each and recorded each setup and its associated V-Curve. When you change setups, you simply choose the desired setup from a list. This flexibility imposes a “price”: If you change optical setups and forget to load the proper V-Curve data, HFR Focus will generally fail to deliver proper focus. In @Focus, a change in setup means that you must independently move the focuser to the correct spot using the RoboFocus control program and your own notes as a guide. You may also need to change @Focus settings to achieve proper operation.

**Image Information.** MaximDL operating with HFR provides more image information than does @Focus. For example, Maxim provides the peak pixel, full width half maximum in x and y, amplitude and width derived from a fitted Gaussian, and a 3-D graph of the image profile. @Focus, on the other hand, provides only maximum pixel and “sharpness” as focusing measures. For those who want the information, Maxim provides the better guide for manual focusing or for monitoring the automatic focus. Indeed, Maxim plus HFR Focus produces a precision tool with which one can investigate the characteristics of the scope and focuser (the Appendix shows some of this type of work). On the other hand, the @Focus program is markedly simpler, and will be preferred by many users.

**Screen Appearance.** This simplicity extends to the screen appearance as well. When using @Focus, the user will see only the CCDSoft window and the CCD camera control tabs. HFR operation generally includes the display of MaximDL and its CCD control tabs, the RoboFocus control program, and the HFR window. While either or both of these can be minimized, during auto focusing the PC screen is more cluttered using HFR. In practice, it is easy to move back and forth between the windows and to minimize unused windows.

### **Typical RoboFocus and Program Settings**

The user will usually establish the internal RoboFocus settings for efficient operation on a particular telescope-focuser combination whether focusing manually or with automatic focusing software. Once the RoboFocus is set, the user will enter additional settings as necessary in the chosen auto-focusing program. Note that the recipes I give below are derived from my own experience: they work for me. Other users may find alternative methods of operation that are better for them.

**RoboFocus Settings.** The RoboFocus stepping motor operates with a configurable internal RoboFocus StepSize (RFSS) of 1-64 microsteps. In general, this setting is set low enough to give the resolution needed for a particular focus system, and high enough to give the range of total movement needed. A directed move of 10 counts at RFSS=4 is the same actual movement as 20 counts at RFSS=2: Both moves have 40 microsteps total movement.

@Focus instructions refer to the Critical Focus Zone (CFZ) which is the focus range over which an image is “perfectly” focused. The CFZ is proportional to the f-number squared and is primarily based on the resolution limit of the scope. In practice, the effective CFZ is often much larger due to atmospheric seeing, under-sampling on the CCD, inaccurate guiding, or any other effect that smears the image. For a f/10 scope, the CFZ is approximately 0.01inch. For “perfect” focusing, you need to be able to make focus movements at least as small as the CFZ. With RoboFocus on the focus knob of an LX200 or on an R&P focuser, the least move is approximately 0.0001-.0002 inch, or about 15x smaller than the CFZ. Thus, one could use an RFSS as large as 10-15 steps (in practice, we usually use smaller step size). For effective use of automatic focusing, it is not necessary to know the particular CFZ value for the system, only that the step size is smaller than the CFZ.

**LX200.** The RoboFocus applied to the LX200 focus knob generally requires RFSS=4 or more to give the full range of focus motion without re-calibration. Total focus range will be about 35,000 counts. RoboFocus backlash setting should be at about 1000 or more microsteps, or about 250 counts for RFSS=4. Direction of backlash correction should be OUT or CCW on the knob, which moves the focus point OUT as a result of moving the mirror IN against gravity.

**R&P.** RoboFocus applied to any Rack and Pinion type focuser (including Crayford style) requires fine steps to give fine control. With an RFSS=2, total focus range will be about 12,000 counts for a five inch travel R&P, and about 2,000 counts for a Crayford focuser (usually only an inch or so travel). RoboFocus backlash setting depends on the focuser, but about 60 microsteps (RFSS=30) is typical. Direction of backlash correction is normally IN so that the focuser will move against gravity.

**@Focus Settings.** The recipe we give here (manual focus, step outward to out of focus, then run @Focus) is a bit different from what is given in the @Focus instructions. We think our process is easier to use; also, we expect customers will develop their own recipes for operation.

In @Focus, you will need initially to set the step sizes (position counts) that @Focus will use. As a start, set the “large step” to about 10 counts (20-40 microsteps) and the small step to 1 count. Be sure and set the backlash in @Focus to zero—RoboFocus is already handling backlash!

Use the maximum pixel value as a guide and find the approximate best focus by “hand”. In this process you will take an image, read the peak pixel value, move the focuser then repeat. You are seeking the focuser position for the highest brightness value. You can use the RoboFocus control program (RFCP) to do the movement, or you can use the stepping available within @Focus where you can make single steps with your mouse. If you have far to go, the RFCP will be faster! When you are near best focus, adjust the exposure and star choice to get about 10,000 counts. Write down the focuser position for this best focus.

Now step outward using the @Focus large steps and take images as you go. Move outward until the max value is about 20% of the starting value. It should take 5-7 steps or so to go from focus to the 20% point. If it takes more or fewer, change the “large” step size in @Focus setup to a value that gives the right step size to make 5-7 steps. Write down this focuser “start” position for future use.

Now choose either sharpness or maximum value as your focus quality parameter, click on @Focus, select move “inward”, and allow @focus to work. @Focus should generate the focus curve and ultimately move to focus. In later focus operations, you step out to the previously determined start position, produce an out of focus image brightness of 1000 or more, then start @Focus.

**HFR Focus Settings.** In HFR Focus, select a field containing a star and exposure that will give a thousand or more counts in a roughly focused image. If you have previously trained the system, select your setup or manually enter the V-curve slopes to be used (or generate a new V-curve, a five-minute process). Set a starting position for focusing (normally entered only once) within a few hundred counts of focus and click the focus button which will cause the system to move to focus. When you are focused, minimize the HFR Focus and RoboFocus windows to reduce screen clutter. To refocus, find a star field with a decent star then just click on focus in HFR Focus-no other input is needed.

In general, we found that HFR Focus yielded slightly tighter focus when the HFR value on the setup screen was set to a lower number (e.g. 3) versus a higher number (e.g. 7). HFR focus works down the V-Curve until it reaches an image with an hfr value close to this setting whereupon HFR Focus takes a series of five images before it calculates the final focus position. A small HFR value setting appears to cause HFR Focus to do a smaller and more accurate extrapolation of the data.