FocusMax

Precision Focusing with FocusMax

Steve Brady
http://focusmax.org

FocusMax

Precision Focusing with FocusMax

CCD Astronomers
Hate Focusing!!

I have been chasing focus demons for many years!

My First Telescope
Circa: 1964

FocusMax

My Astro-Cameras

1960's

1970's

1980's

My Astro-Cameras

ST-8 XME

1990's

How do you focus this thing ???

FocusMax was developed by Steve & Larry to address a missing link in observatory automation

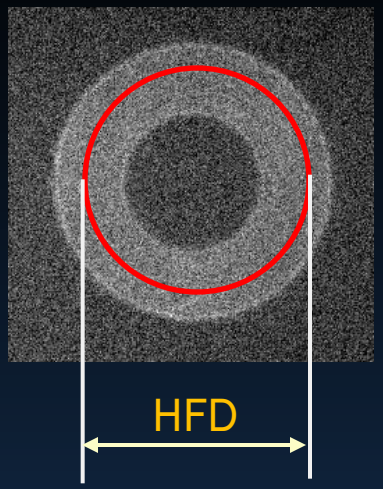
FocusMax Goals

- Accuracy equal to or better than manual focusing
- Fast so that valuable observing time is not lost
- Robust so that the user can expect it to arrive at the correct focus even in marginal conditions
- Capable of accommodating a wide range of initial out of focus star diameters
- Operate as an automation client for unattended observing (ACP, CCAP, CCDC,....)

Degree of Focus Metric

Half Flux Diameter (HFD)

The diameter of a circle centered on the unfocused star in which half of the total star flux is inside the circle and half is outside



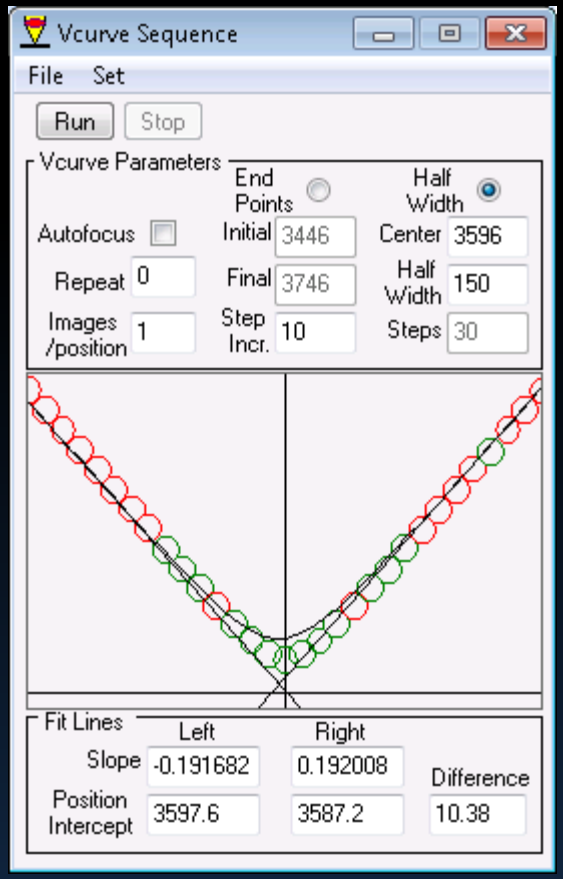
FocusMax

Degree of Focus Metric

- HFD units are CCD pixels
- Relatively insensitive to variations in seeing
- Accurate over a wide range of unfocused star diameters
- HFD is determined by integrating all of the flux from the unfocused star

Vcurve

FocusMax



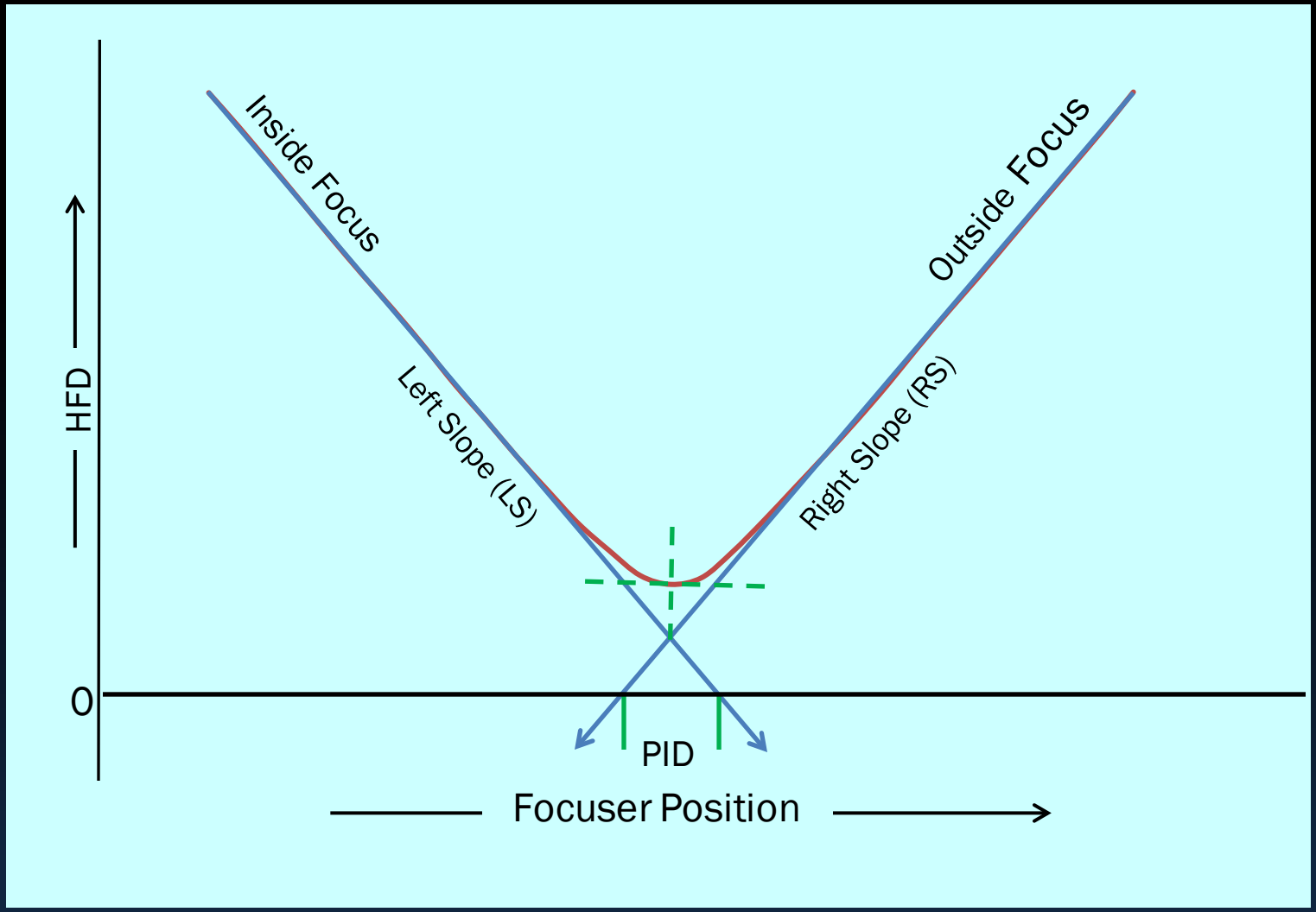
A plot of HFD vs. focuser position yields a ‘V’ shape

The ‘wings’ of the curve are linear which are dependant on

- optical f/ratio
- CCD pixel size
- focuser gear ratio
- etc.

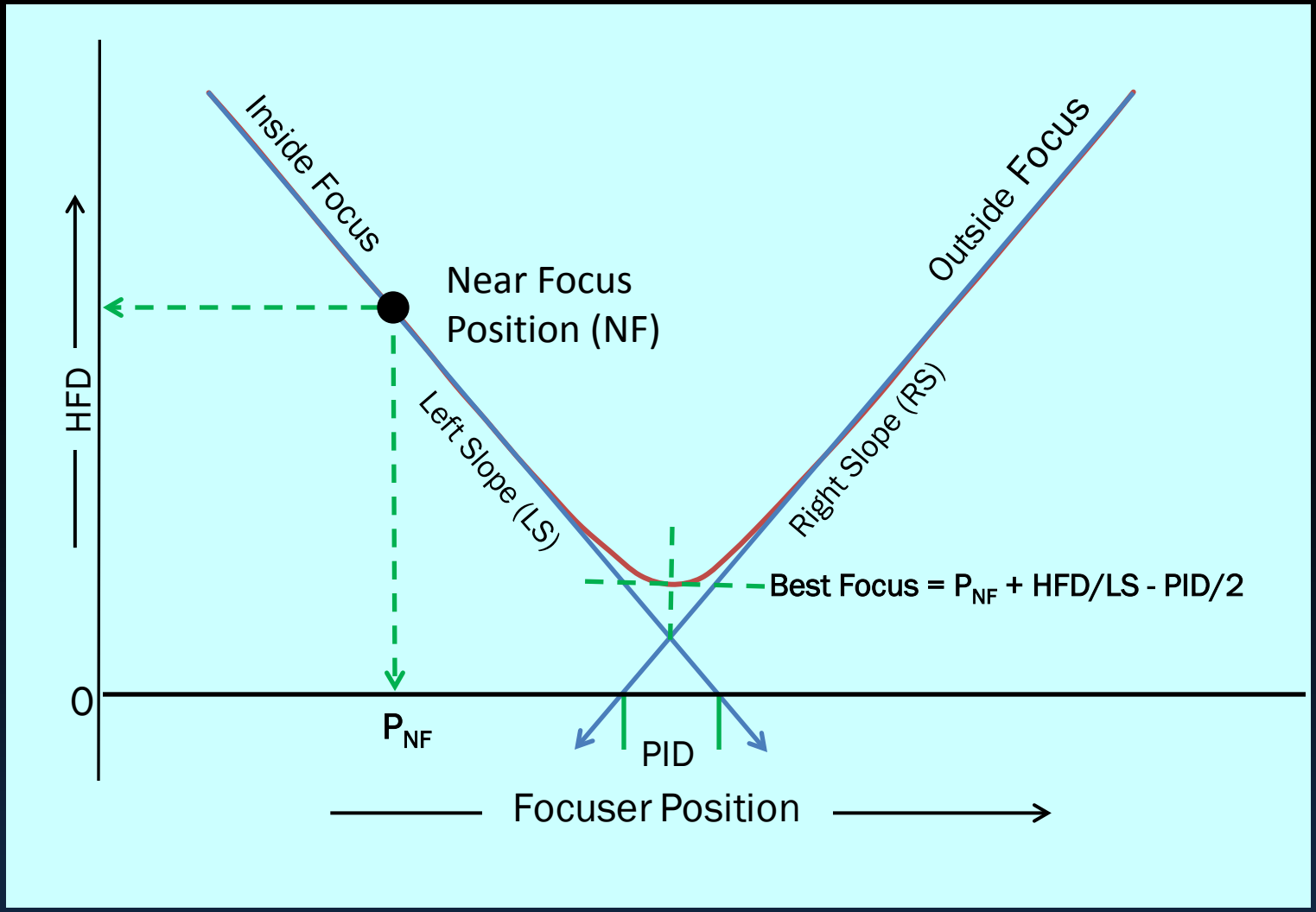
Vcurve

FocusMax



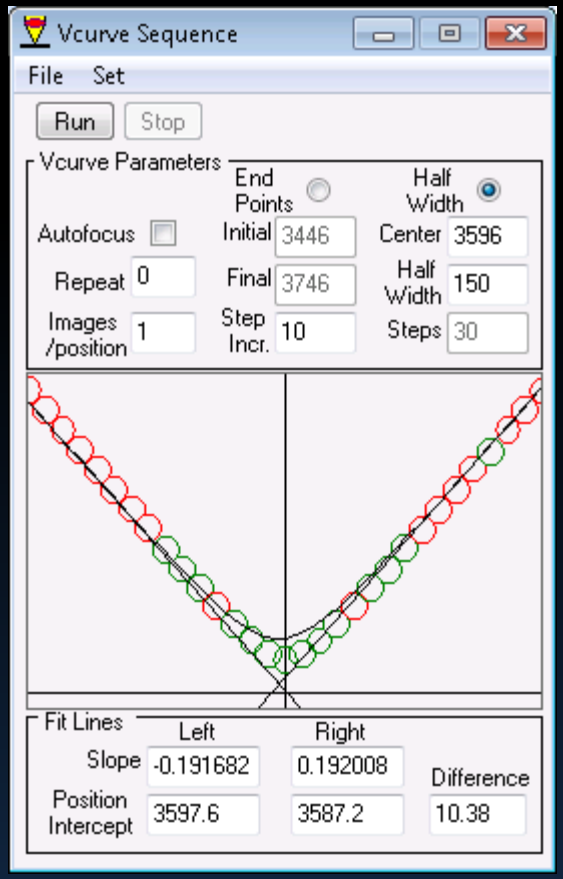
Vcurve

FocusMax



FocusMax

Vcurve

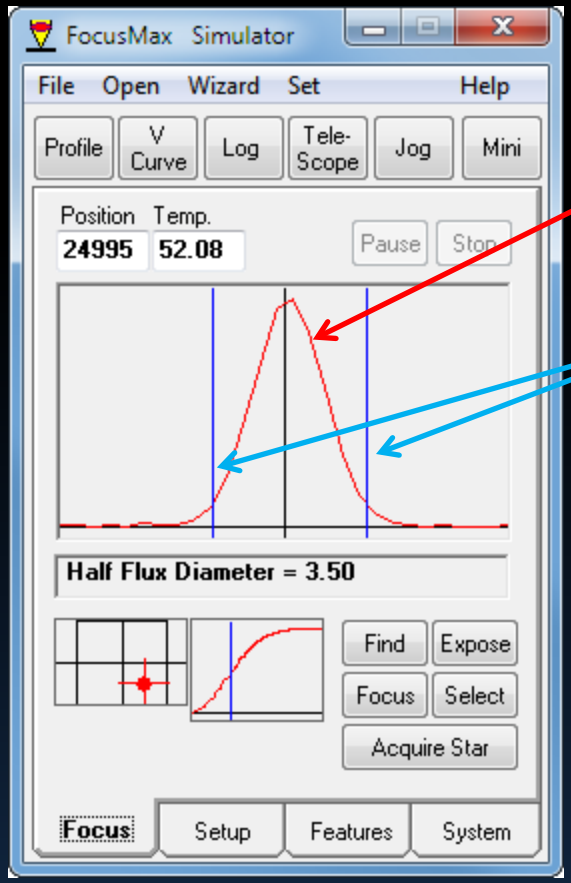


FocusMax automatically determines:

- Slope of the Right & Left lines
- Position Intercept
- Position Intercept Difference (PID)

FocusMax

Focus Tab

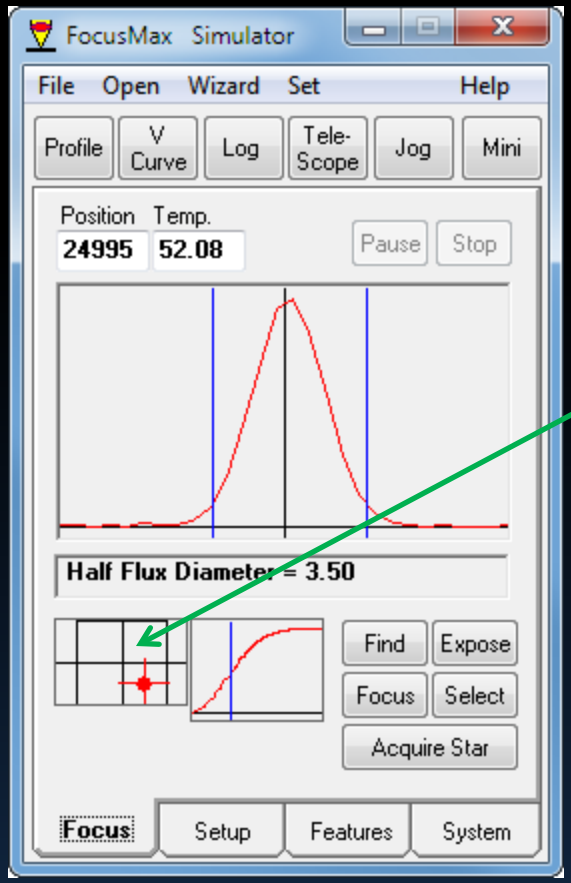


Vertical bin of the sub-framed star

Detected star boundaries

FocusMax

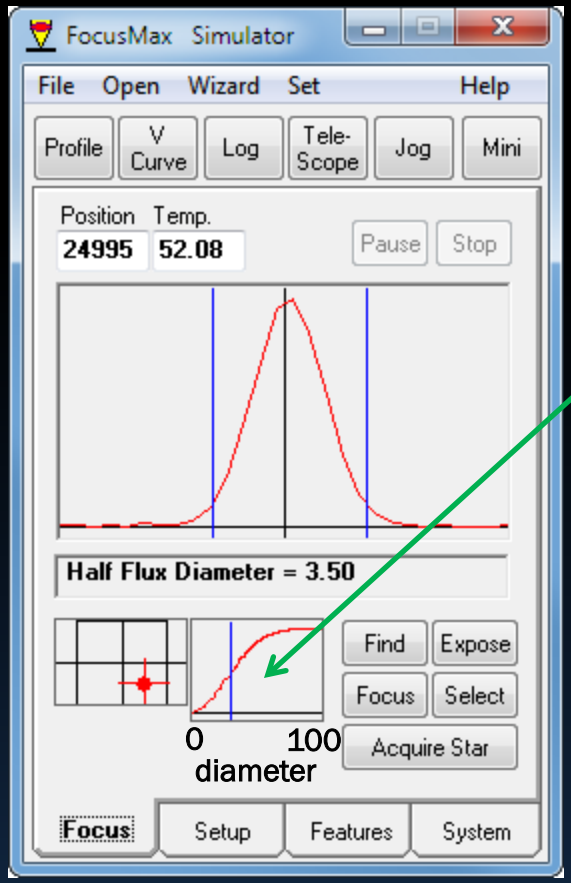
Focus Tab



Location of star on camera chip

FocusMax

Focus Tab

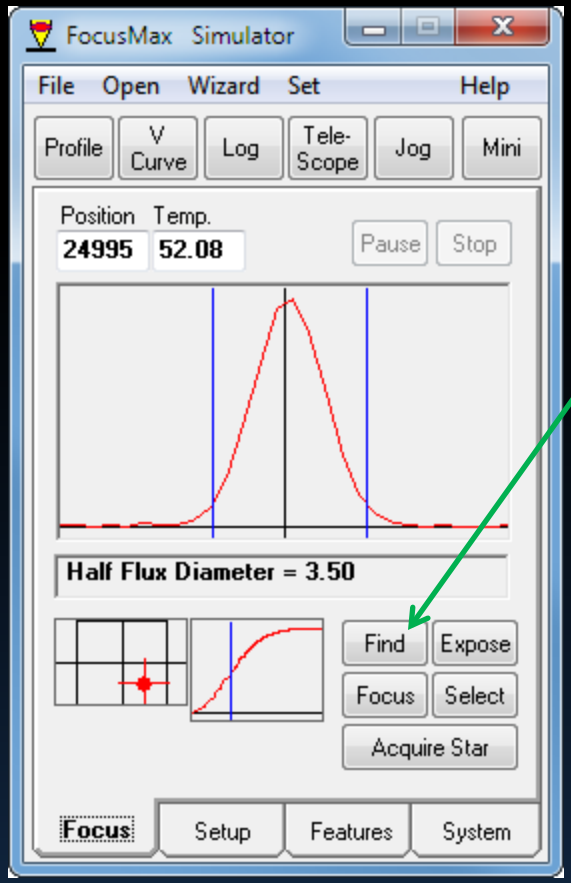


Flux integral plot of the star diameter along the x-axis and integrated flux along the y-axis.

HFD is the point marked with a vertical line

FocusMax

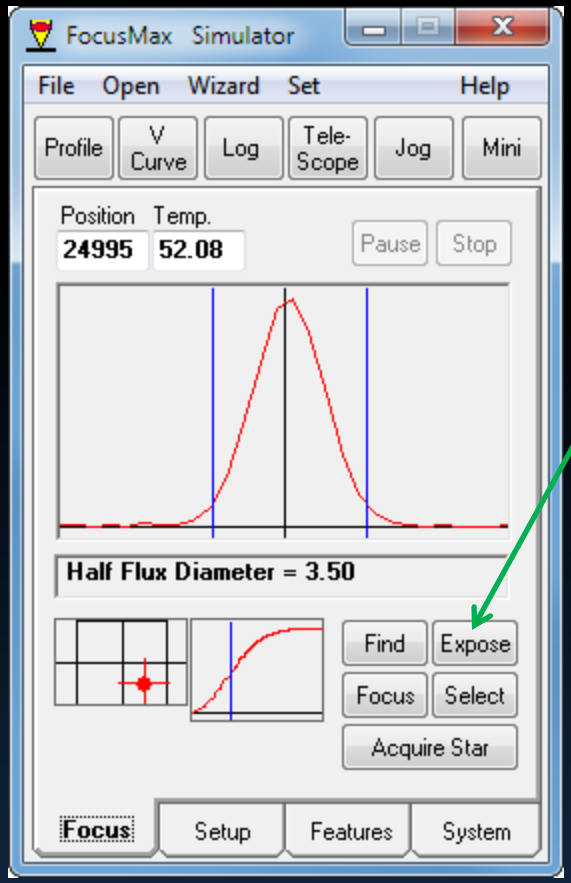
Focus Tab



Find button :

- Take a full frame image
- Find brightest star
- Subframe star

Focus Tab



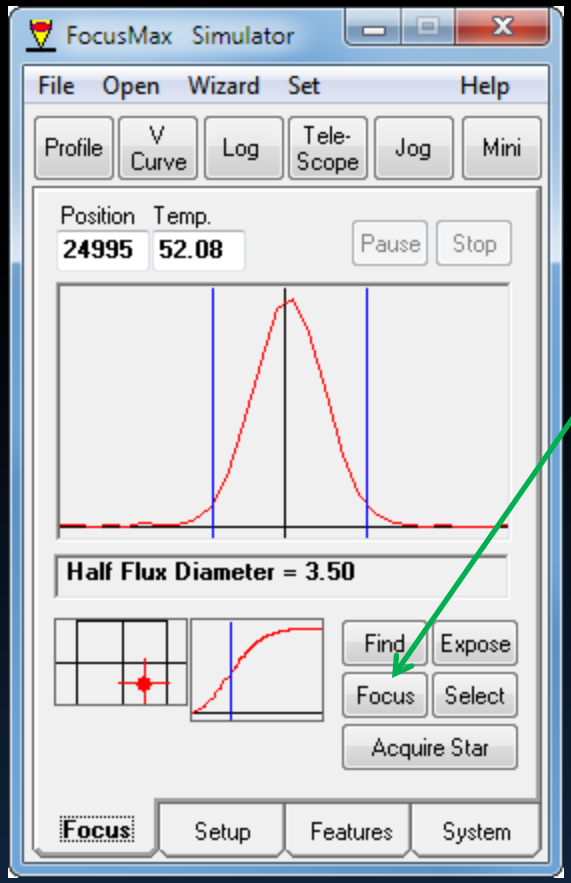
Expose button :

- Take a subframe image centered on star from 'Find' star process

Star position on CCD must be known

FocusMax

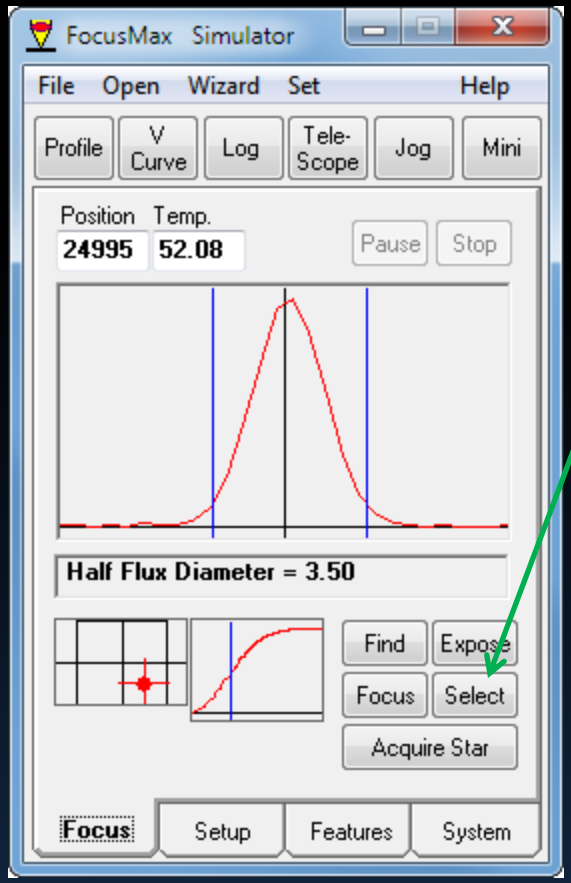
Focus Tab



Focus button:

- Take a full frame image
- Find brightest star in image
- Subframe star
- Move focuser to Start Position
- Move focuser to Near Focus Position
- Take repetitive subframe images
- Measure HFD and calculate Best Focus position

Focus Tab



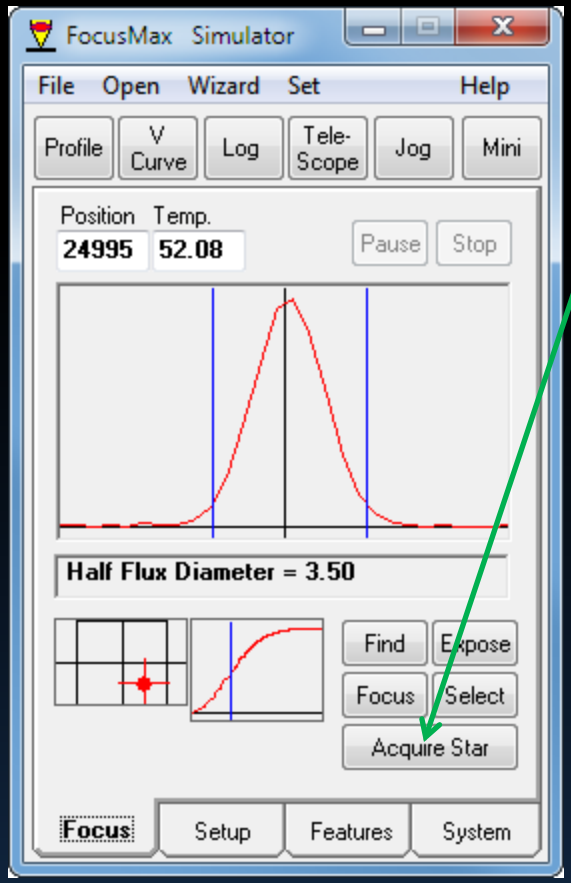
Select button (MaxIm only):

- Take full frame image
- User clicks on target star with mouse
- Autofocus is initiated

- Useful if user does not want to leave present field
- Blobs (deep sky objects) will confuse FocusMax and report larger HFD values (they appear as out of focus stars)

FocusMax

Focus Tab



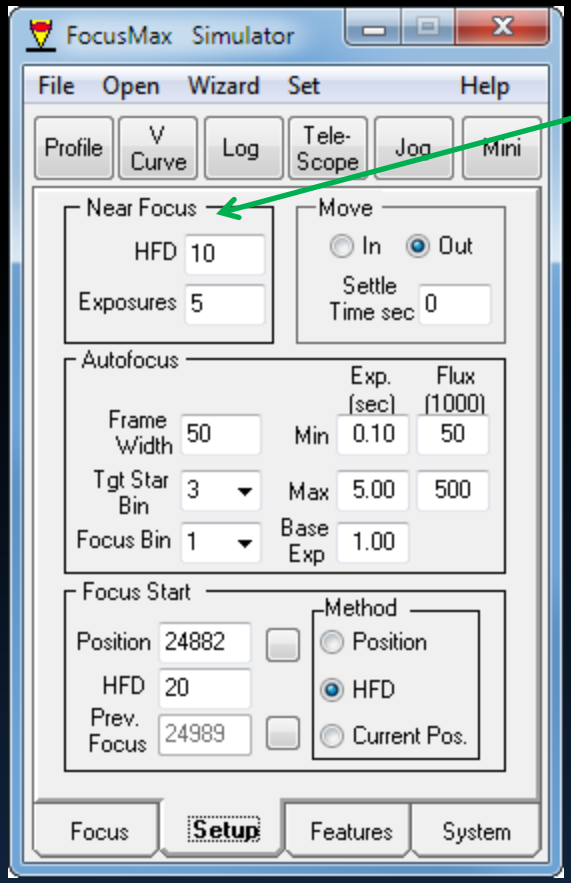
AcquireStar button:

- Take image and plate solve current telescope position *
- Look up target stars from catalog
- Slew telescope
- Center target star
- Autofocus
- Return slew
- Take image and plate solve telescope position *
- Fine tune pointing to user defined error

•Requires full feature PinPoint (http://www.dc3.com/)

FocusMax

Setup Tab

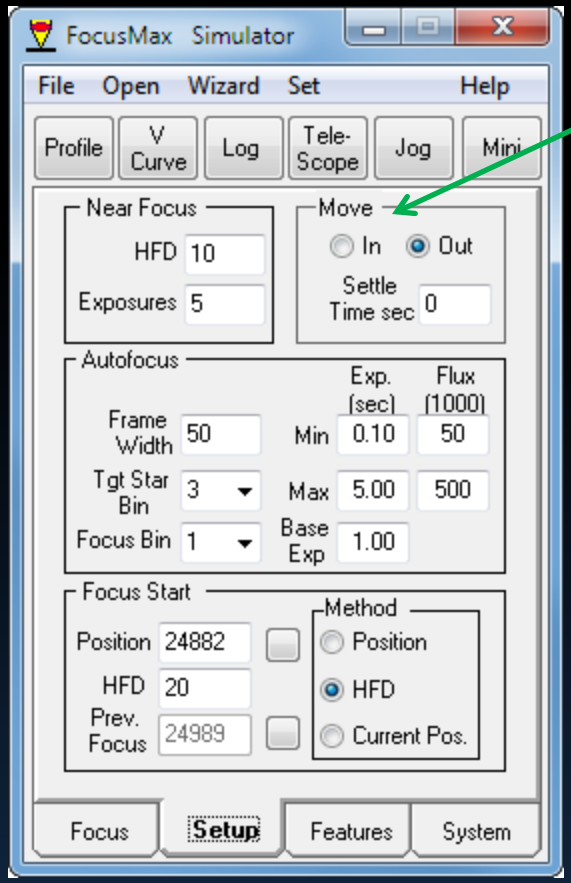


Near Focus:

- HFD - position used to determine focus position
- Exposures - the number of subframe images used to determine the final focus position

FocusMax

Setup Tab

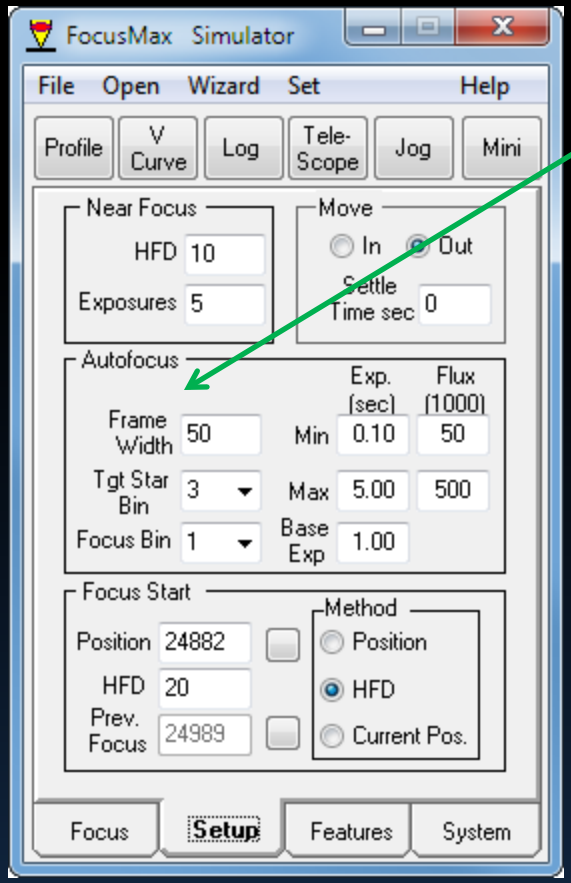


Move:

- Set focuser move direction and settle time to prevent image wiggle
- Focuser movement will be toward focus to eliminate backlash
- Move direction is often set to move load against gravity

FocusMax

Setup Tab

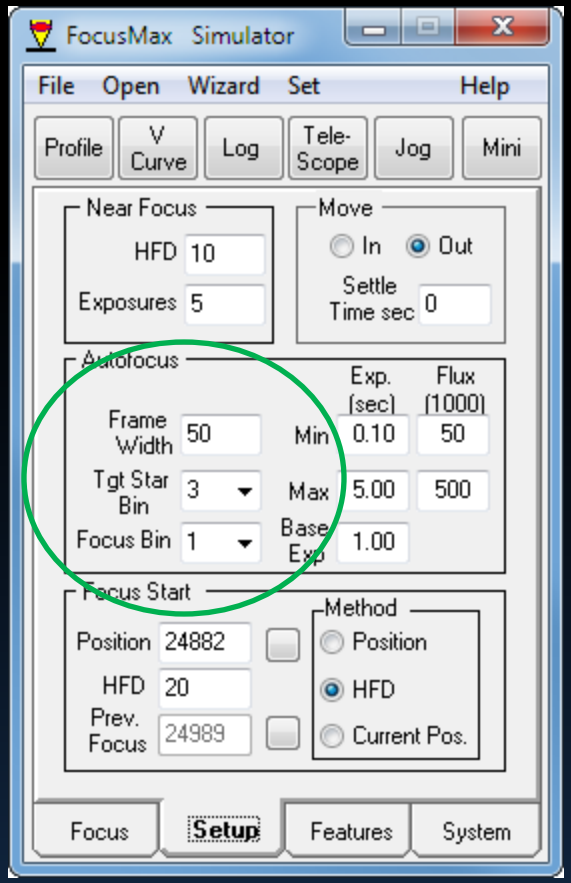


Autofocus:

- Initial subframe width
- Target star binning (1 – 4)
- Focus binning (1 & 2)
- Min/Max Exposure
- Min/Max Flux
- Base exposure

FocusMax

Setup Tab

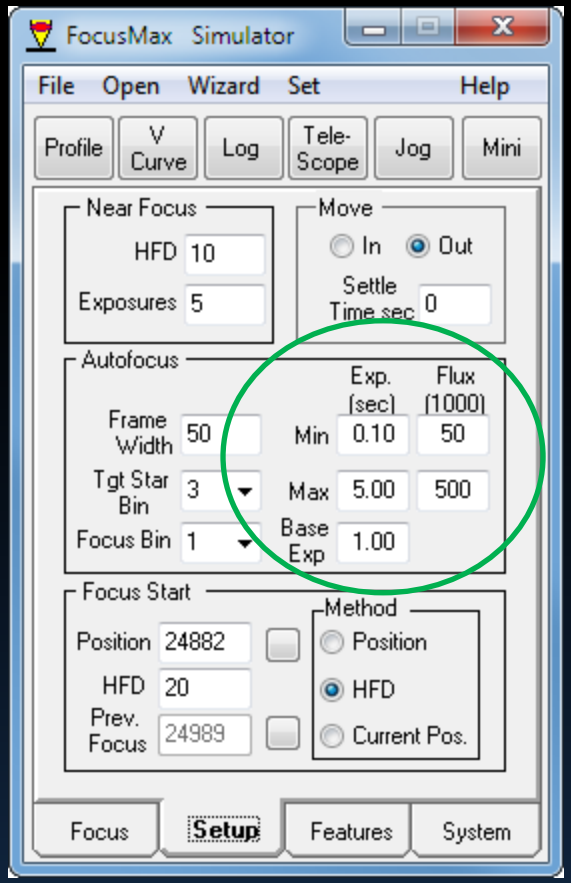


Autofocus example:

- Star will be found using 3x3 binning
- Focus Bin will be 1x1
- Initial subframe will be 50 x 50 pixels

FocusMax

Setup Tab



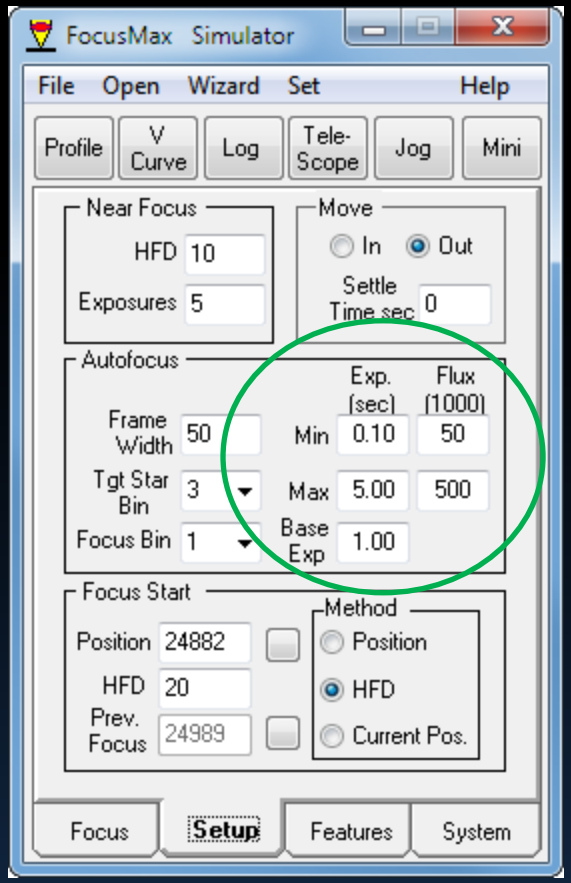
Autofocus example:

- First exposure will be 1.00 sec and may be adjusted up or down to meet the midpoint of the Flux range of 50K – 500K

- Last resort:
  - If the star is too dim then it will attempt to target Min Flux
  - If the star is too bright it will attempt to target Max Flux setting

FocusMax

Setup Tab



Autofocus exposure calculation:

Target Flux = (500K + 50K)/2 = 275,000

Base Exp. = 1.0 sec

Measured star Total Flux = 536,401

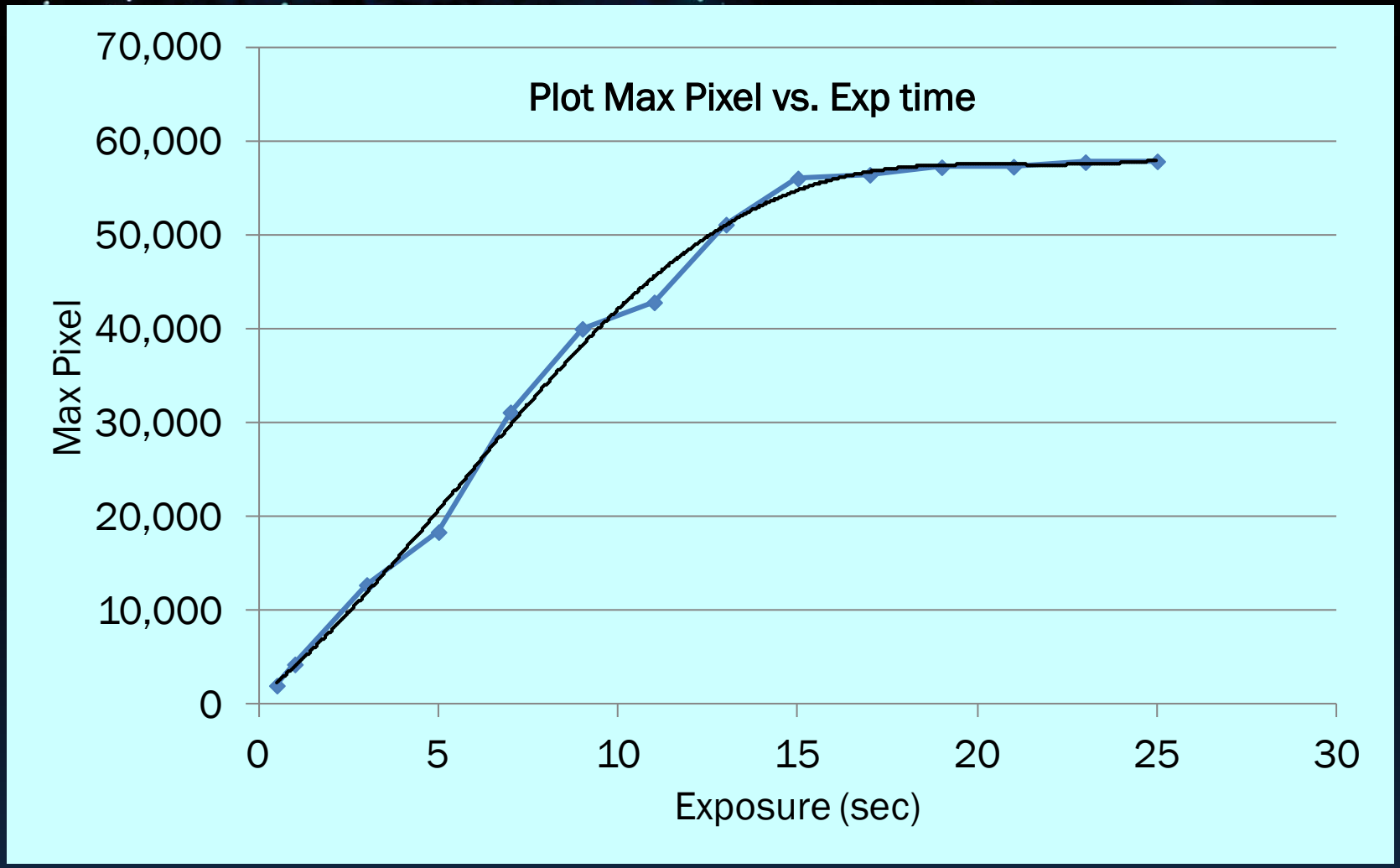
New Exp = 1.0 x (275K/536K) = 0.51 sec

Max Flux Setting (CCD Linearity Test)

FocusMax

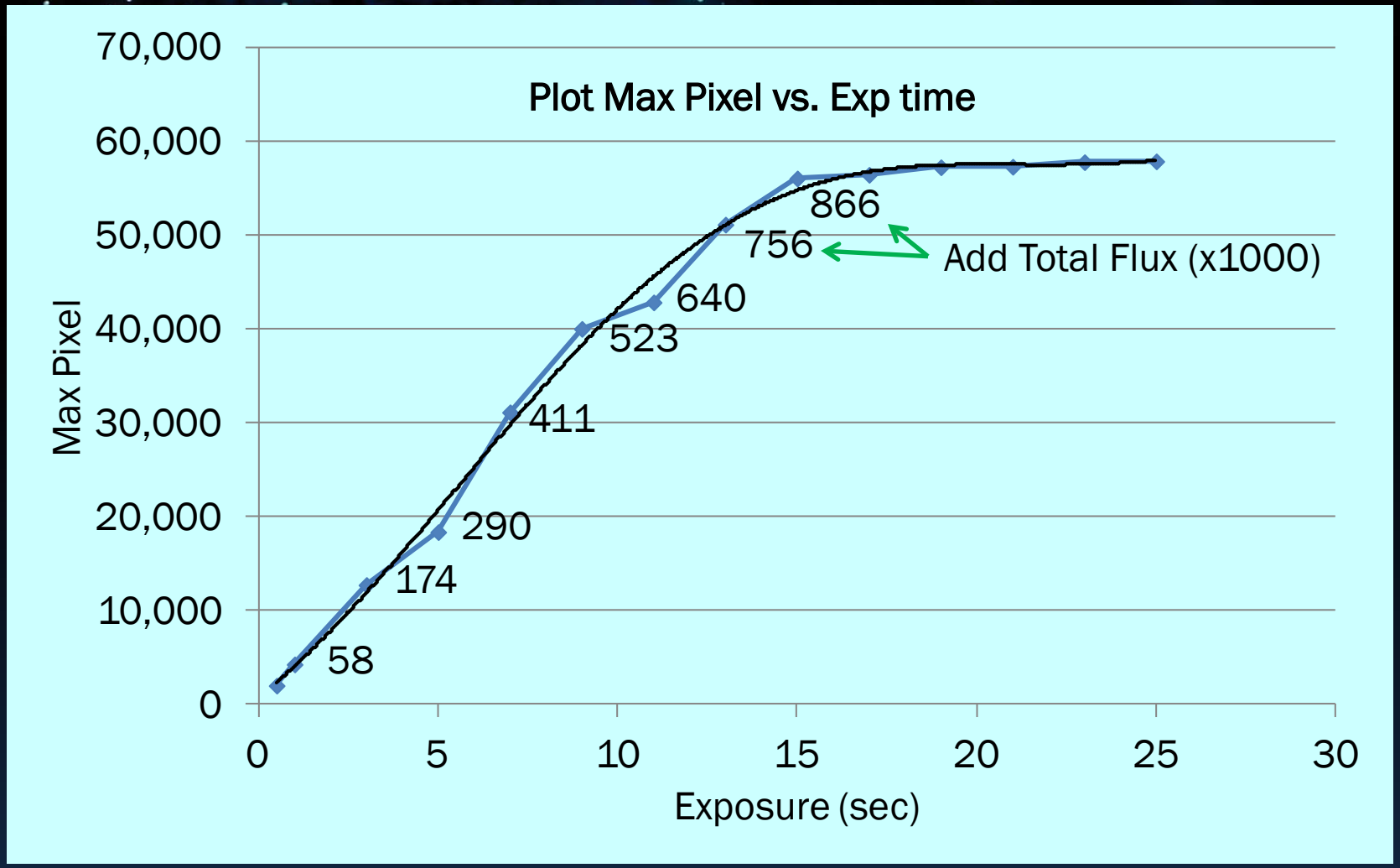
- Select moderately faint, isolated star near the zenith
- Focus telescope
- Set Min Flux to 0 on Setup Tab
- Enable CCD Central Region on Features Tab and set to 25% (or smaller)
- Set Base Exp. to 0.1 sec
- Press Find and verify that FocusMax identifies the target star
- Note the Exp., Max Pixel and Total Flux in Log
- Increase Base Exp. to 0.5 press Find
- Increase Base Exp. To 1 sec and repeat in intervals of 2 sec until reach 30 sec (can be automated in MaxIm using Autosave feature)
- Construct a plot of Max Pixel vs. Exp. time

Max Flux Setting

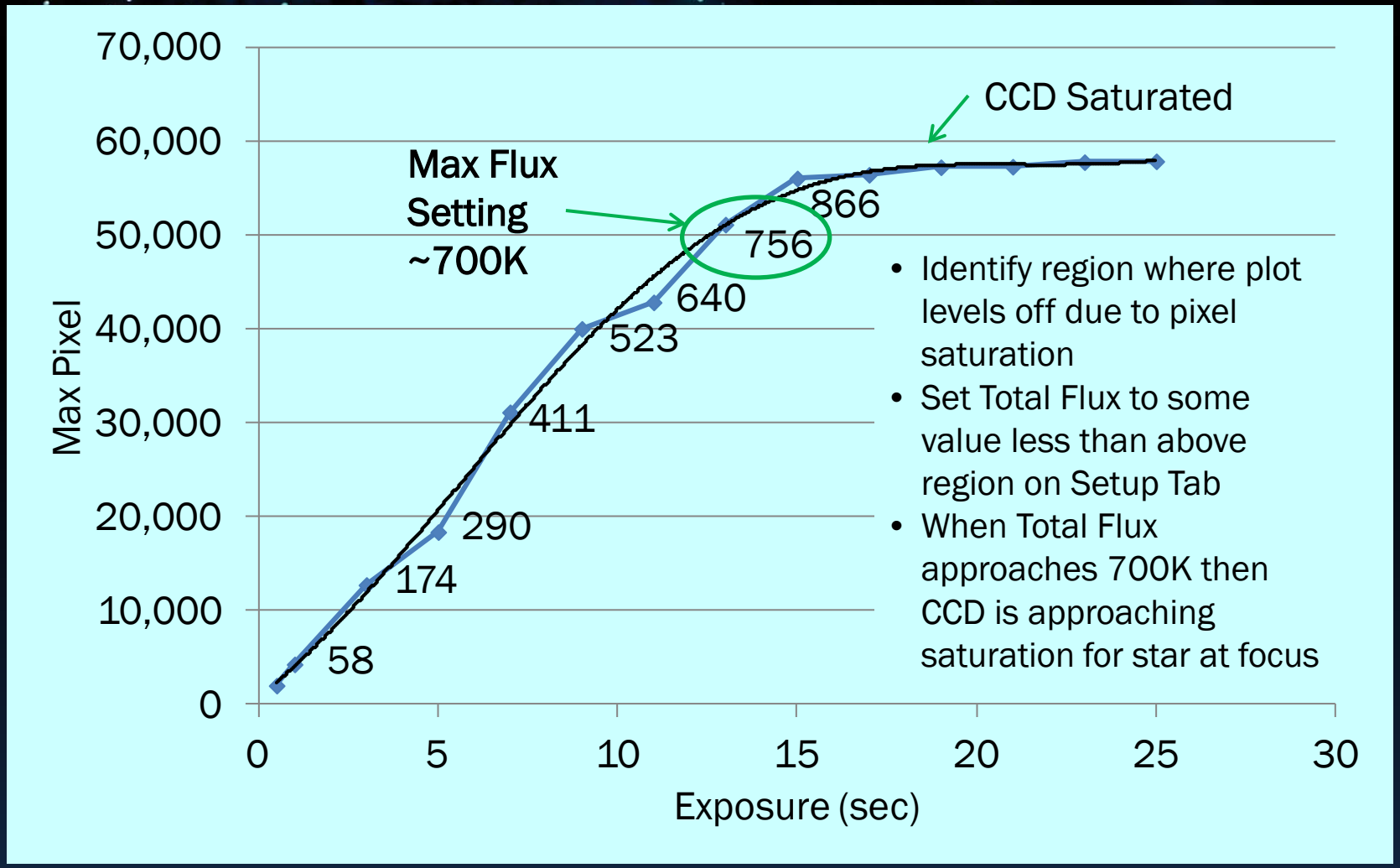


Max Flux Setting

FocusMax

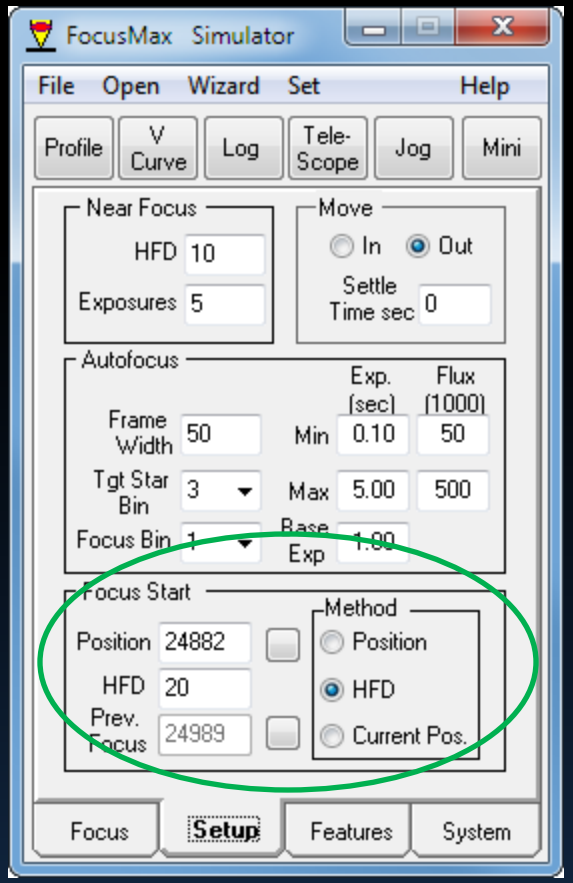


Max Flux Setting



FocusMax

Setup Tab

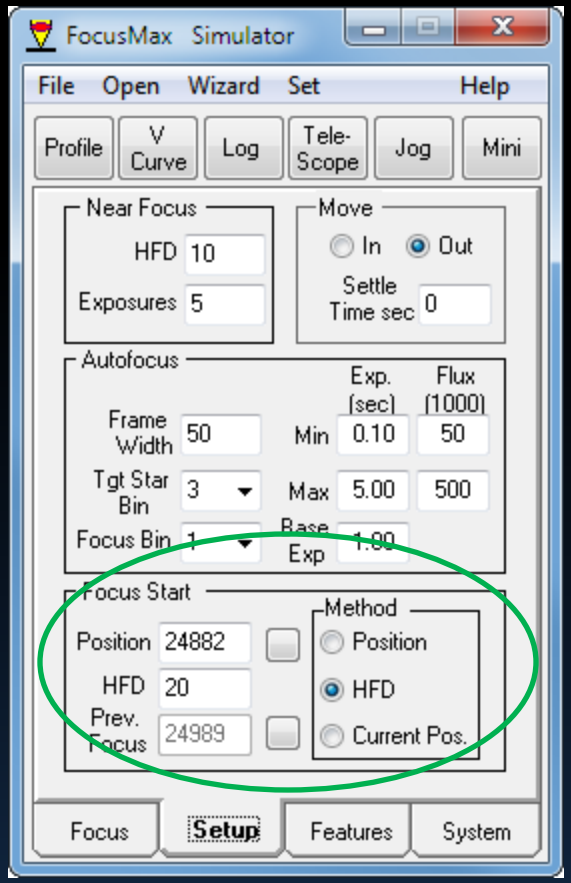


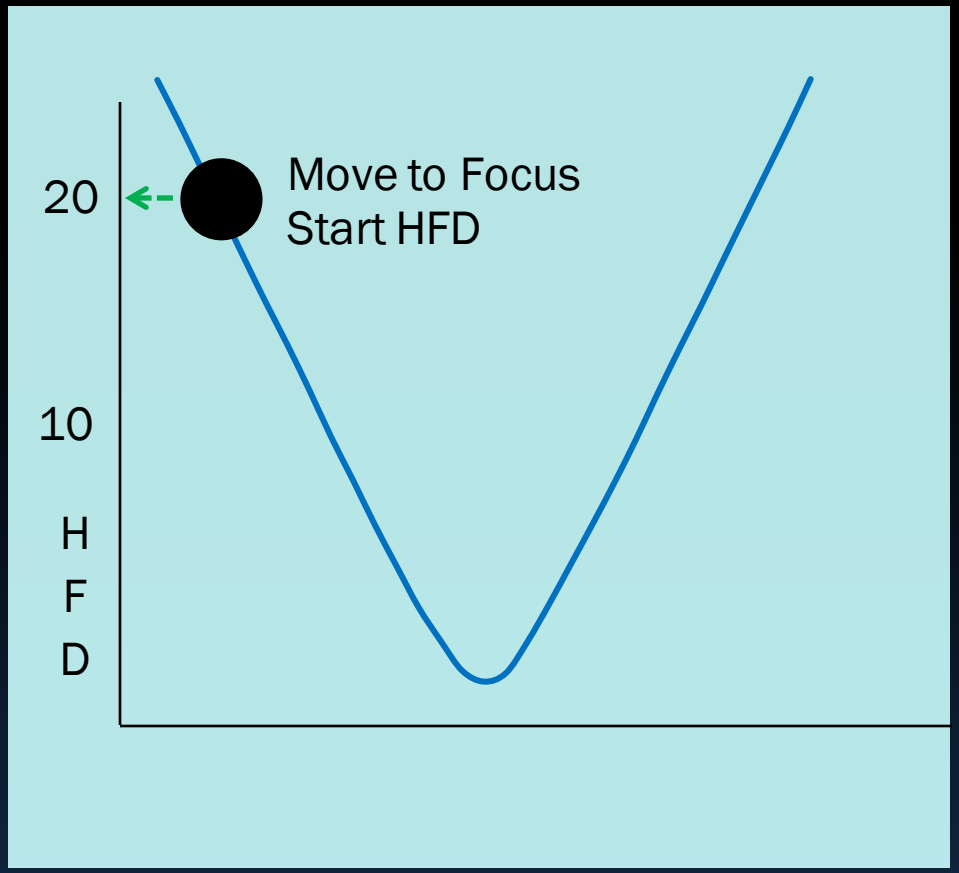
Focus Start:

- **Position** - move focuser immediately to the listed position (fastest method but position must be current from recent autofocus run)
- **HFD** - requires finding the focuser at HFD setting (medium speed - preferred)
- **Current Position** - start at current focuser position and then find HFD position (slowest)

FocusMax

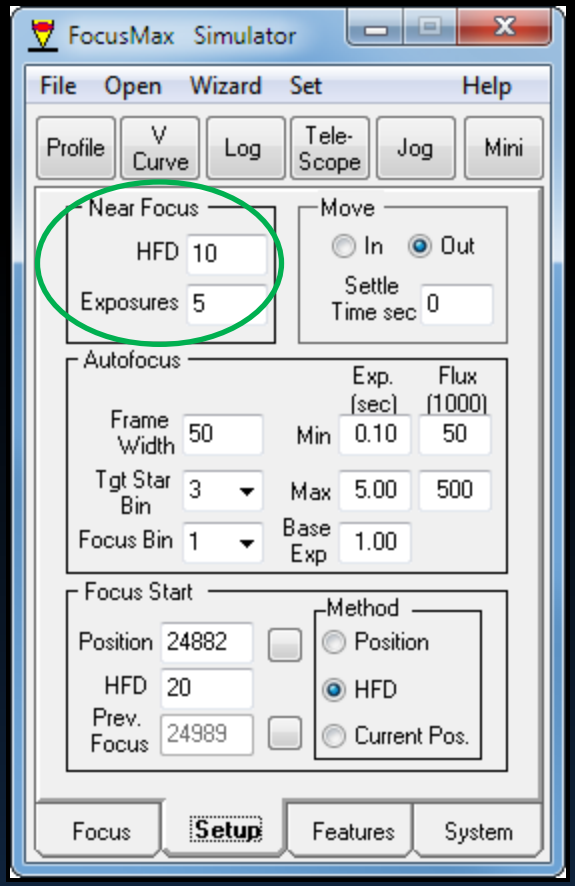
Setup Tab

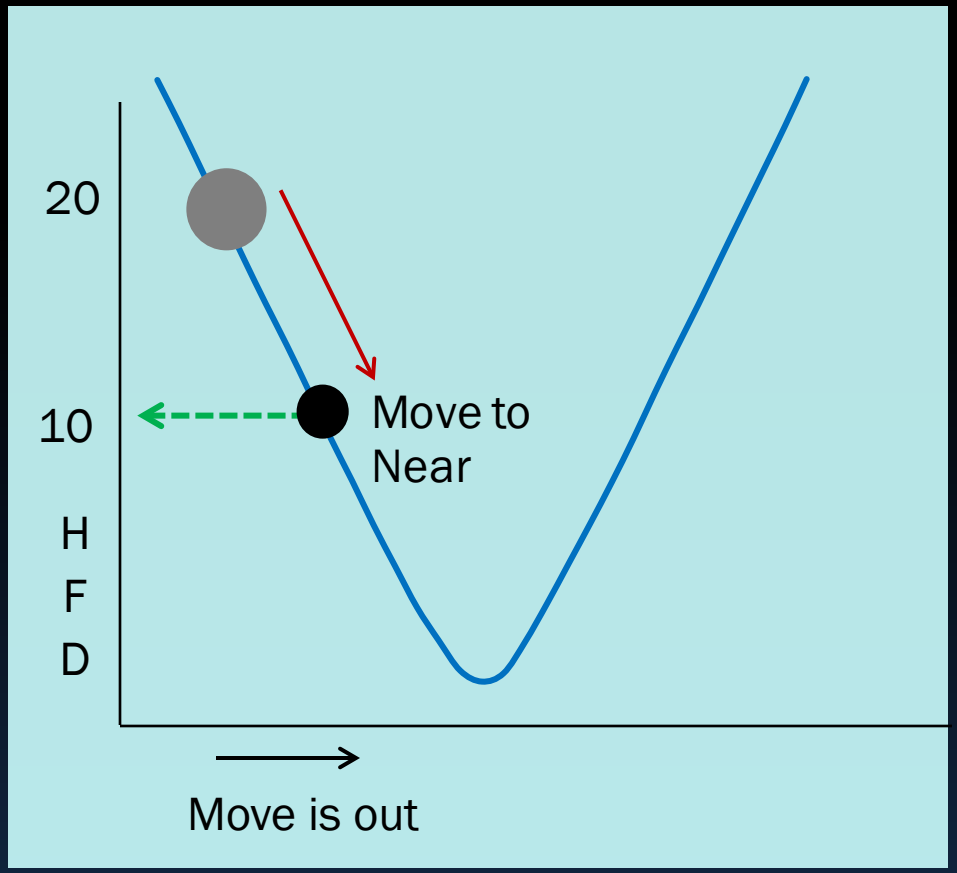




FocusMax

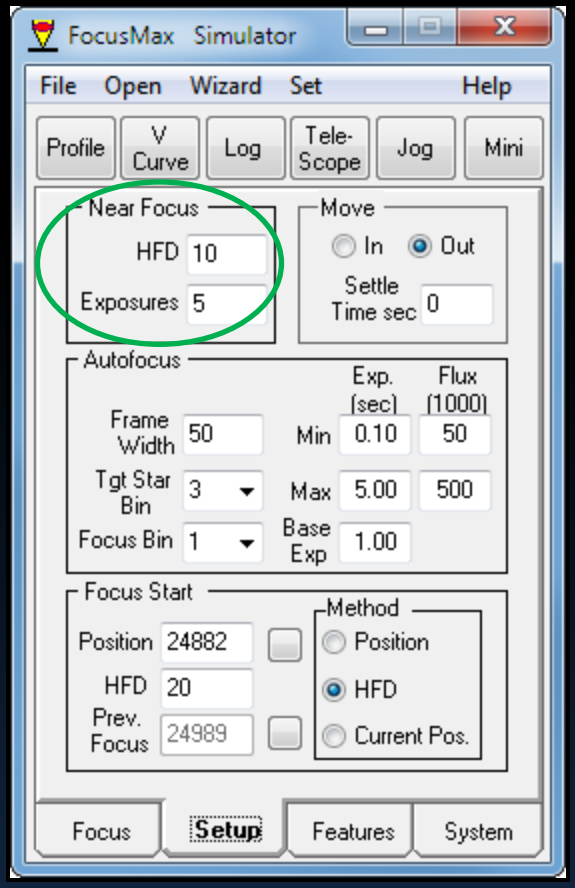
Setup Tab

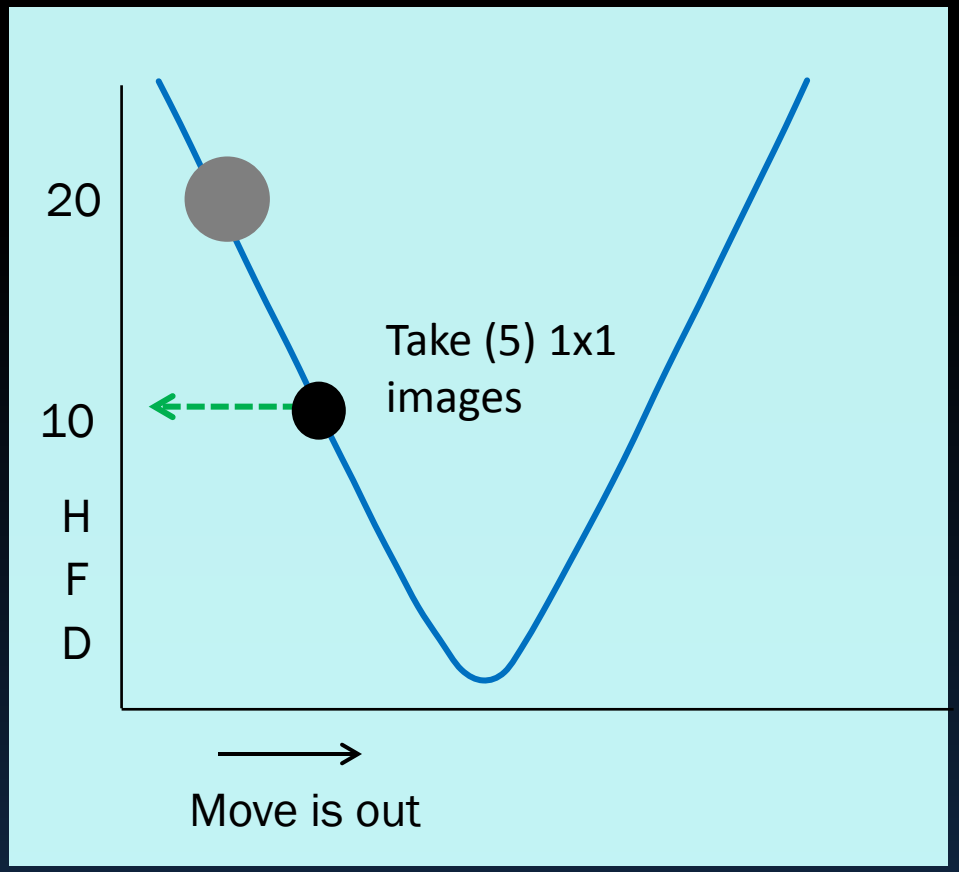




FocusMax

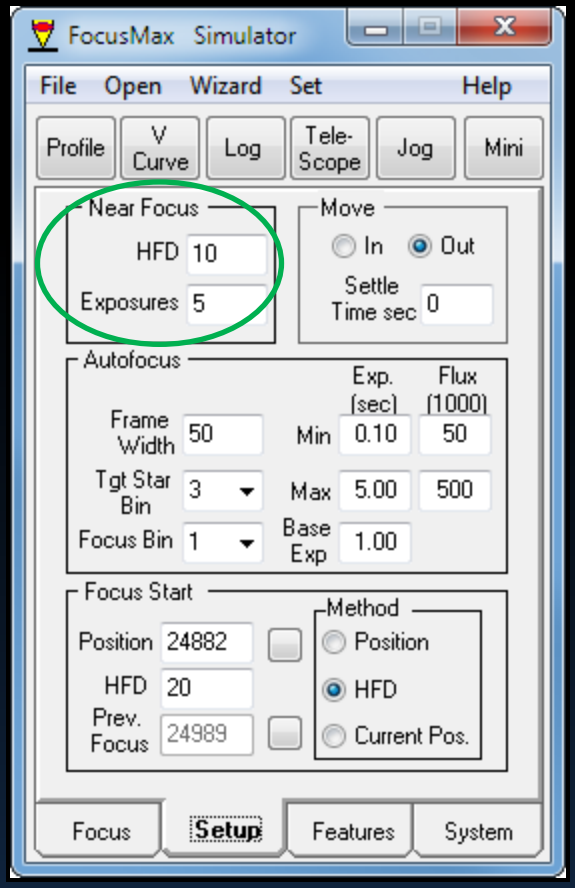
Setup Tab

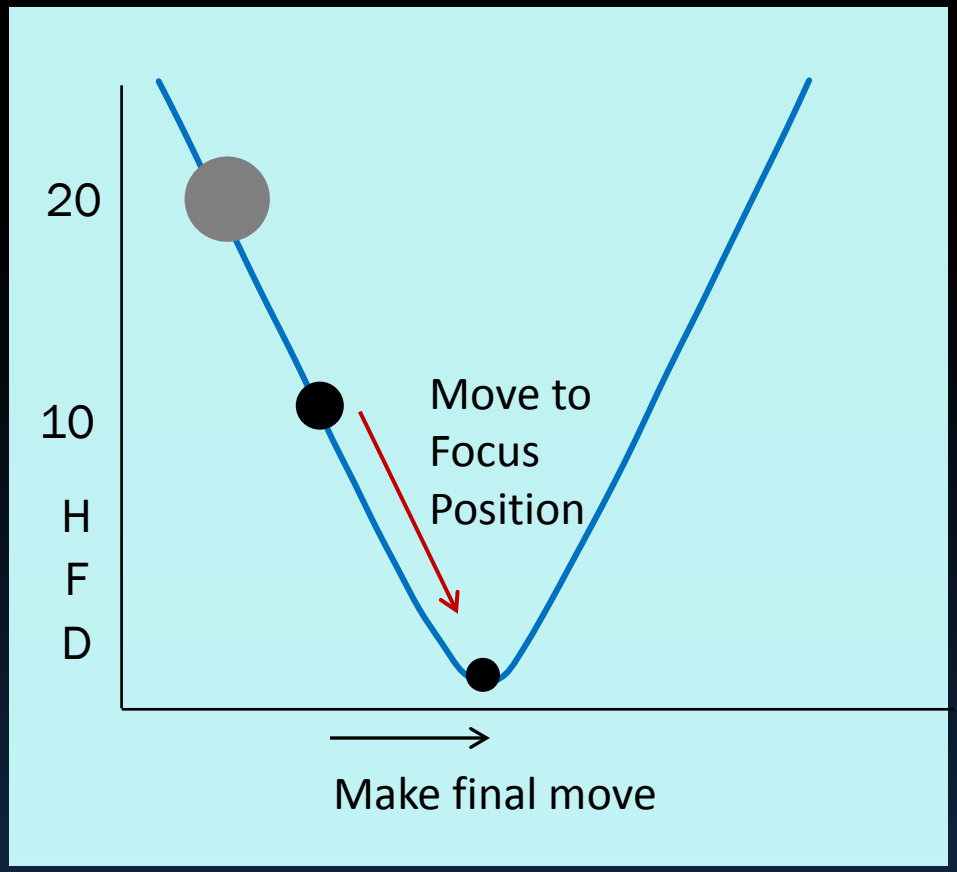




FocusMax

Setup Tab





FocusMax Tour
Features Tab

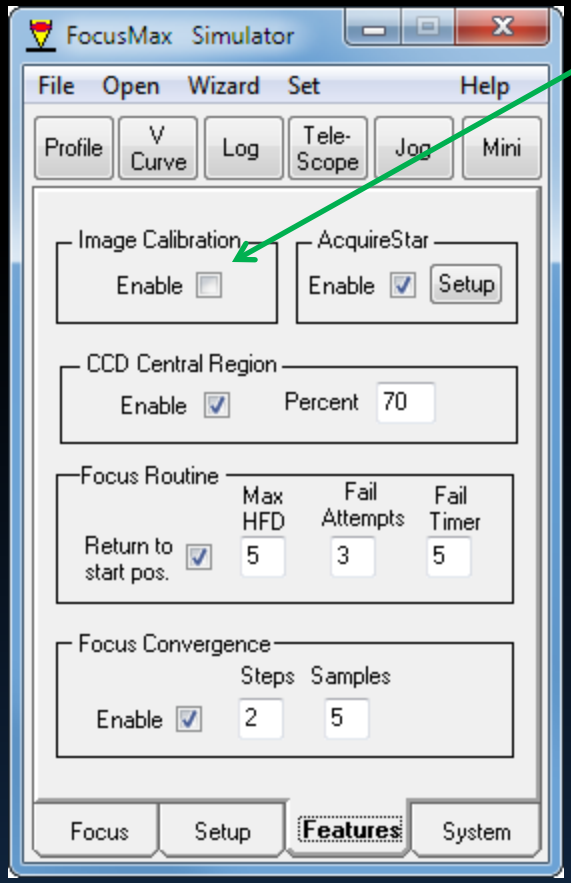


Image Calibration:

Help eliminate 'hot pixel' that may cause FocusMax to think a it is a star for focusing

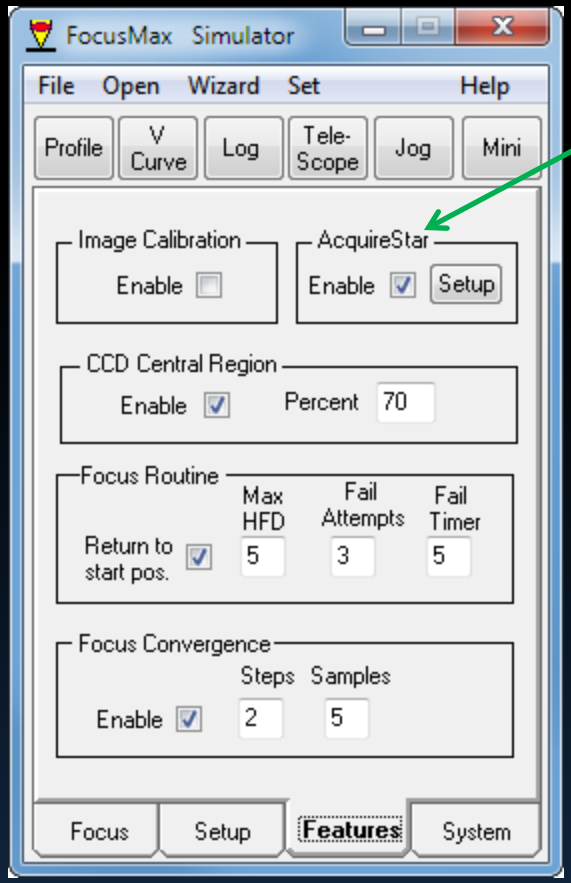
MaxIm

- Create a set of dark frames in the Min/Max exposure range and binning
- Create a set of bias frames
- Save frames to a directory
- Load frames into MaxIm using Set Calibration

CCDSoft

- FocusMax will utilize Image Reduction: AutoDark with each frame taken

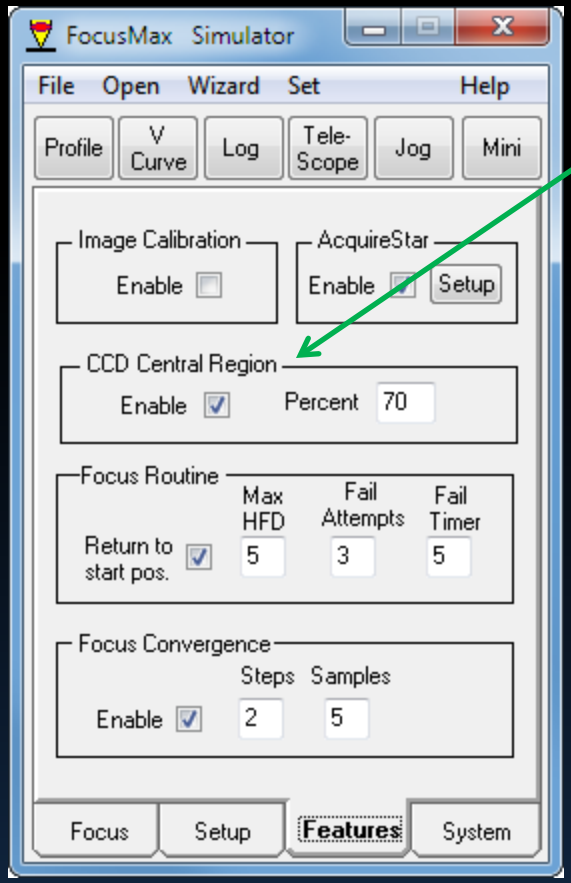
Features Tab



AcquireStar:
Automated target star acquisition, star centering and autofocus

FocusMax

Features Tab

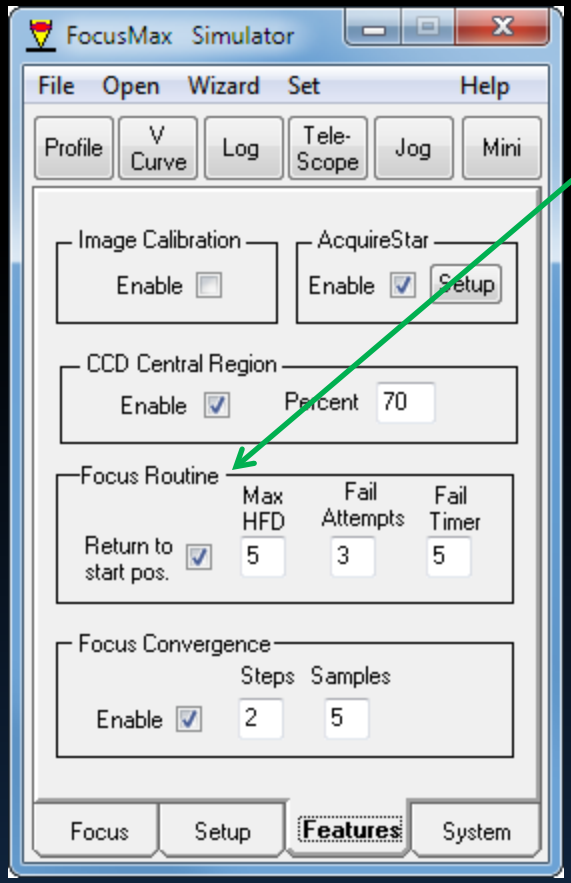


CCD Central Region:

- Limit the area for target star detection to central region on the CCD
- Reduces impact of curvature of field and coma
- Recommended for wide field / large format cameras

FocusMax

Features Tab



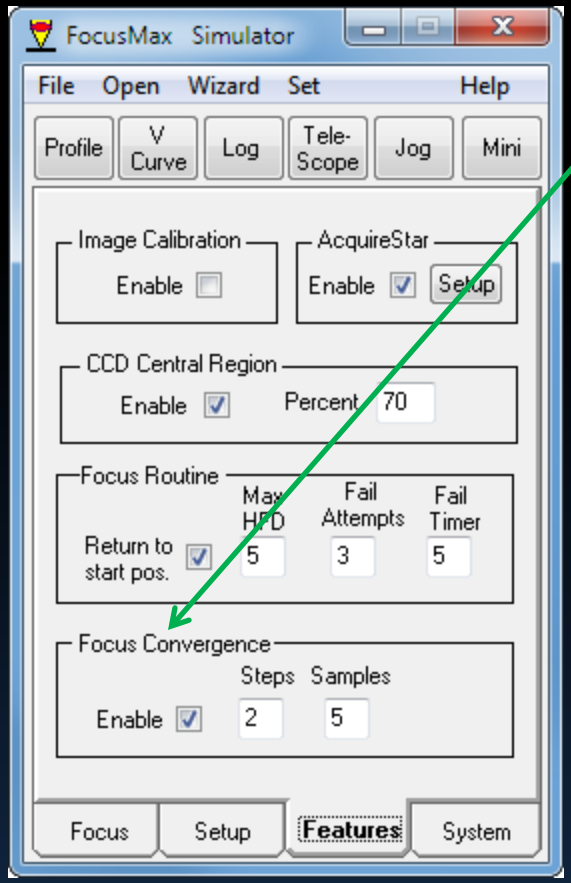
Focus Routine:

- Return to Start Position triggered by:
  - Autofocus HFD > Max HFD
  - Lost star
  - Clouds
- Max HFD - largest allowed HFD
- Fail Attempts - number of tries to achieve focus
- Fail Timer - delay before autofocus routine is attempted again (clouds)

Useful for unattended all night runs

FocusMax

Features Tab



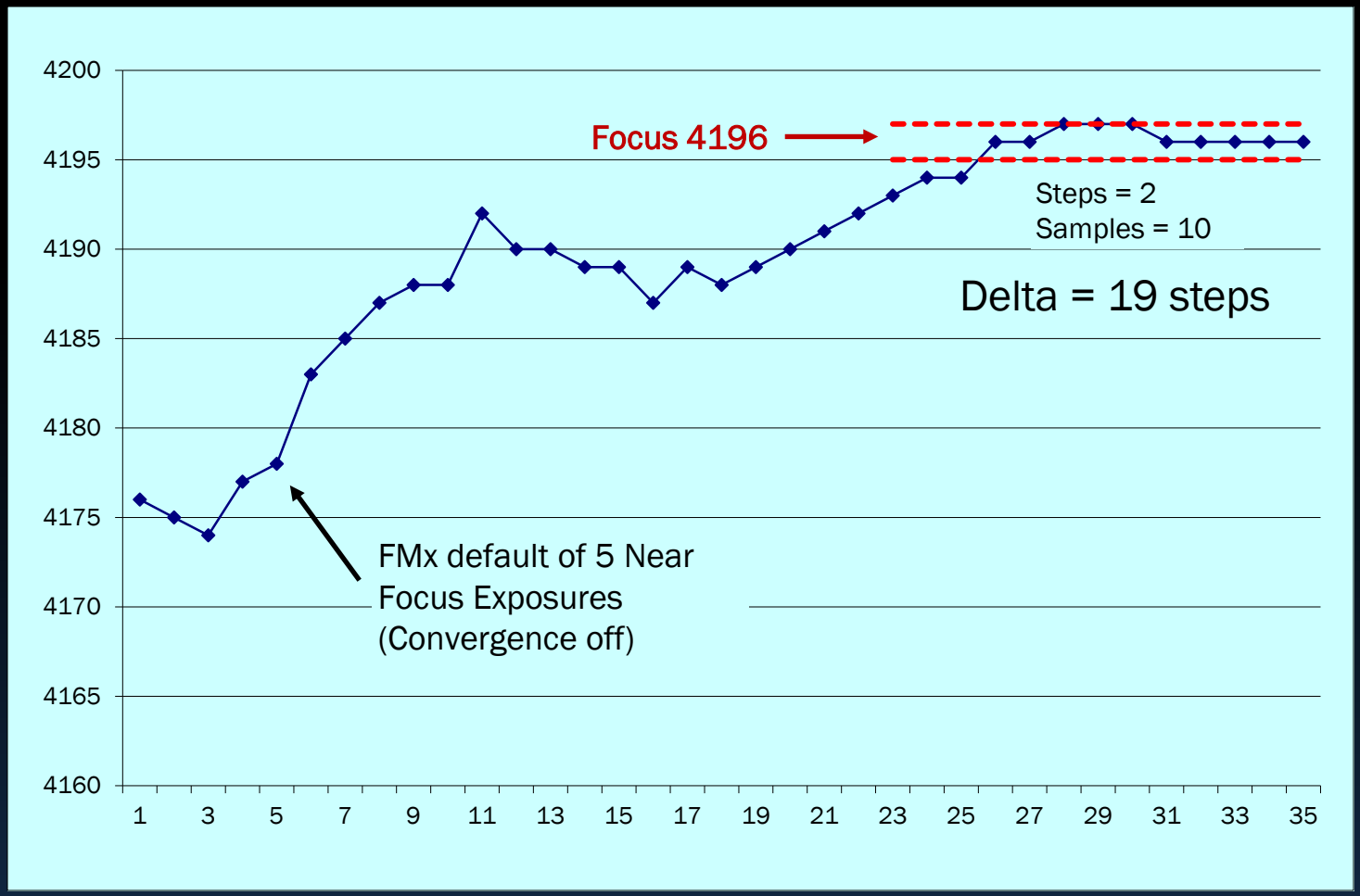
Focus Convergence:

Will determine the best focus position by taking repeated subframe images until the average HFD falls within a user defined tolerance

- Steps - the number of focuser steps (units) that the average HFD must fall within
- Samples - the number of consecutive measurements that must fall within the above Steps setting before making the final focuser move

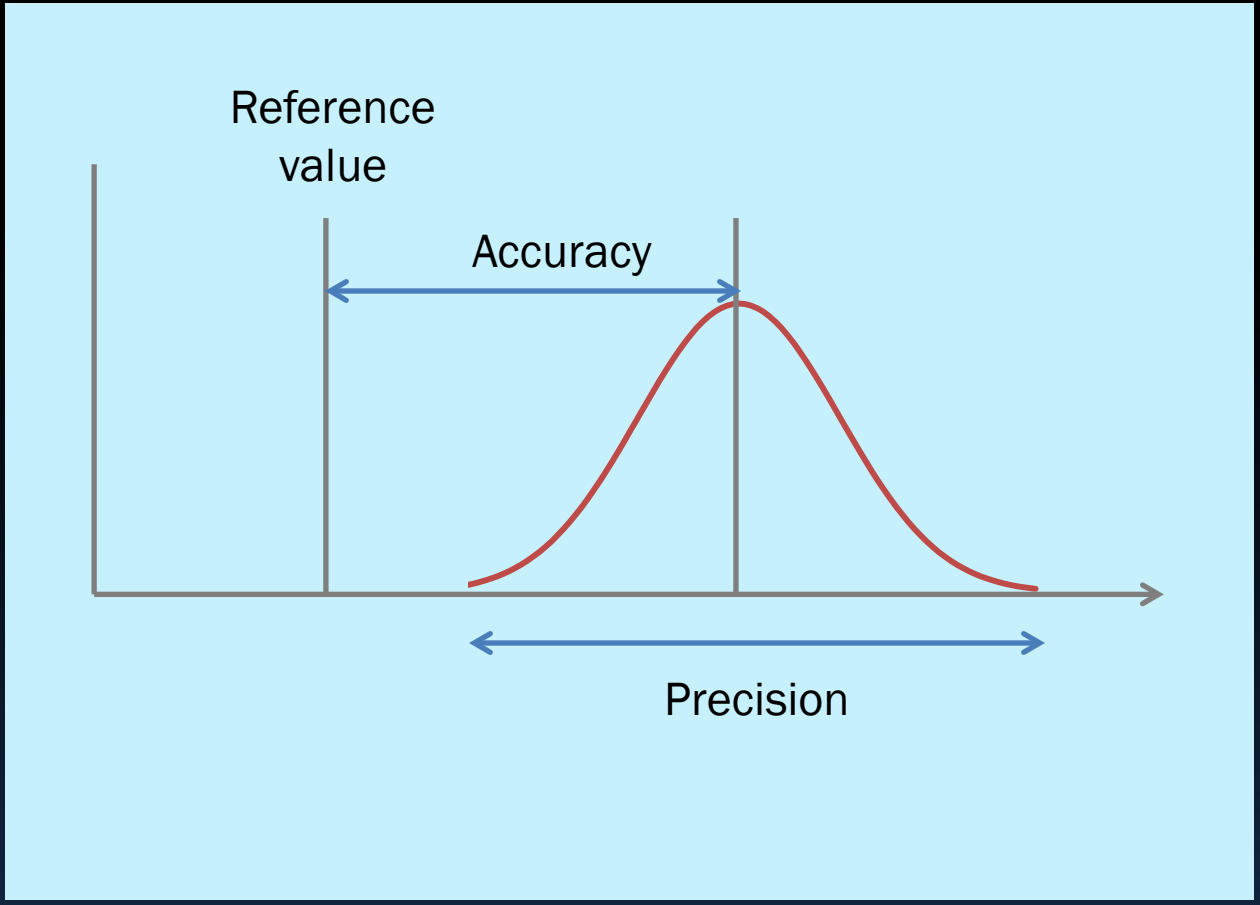
FocusMax

Focus Convergence



FocusMax

Accuracy & Precision



FocusMax

Accuracy & Precision

High accuracy
Low precision

Low accuracy
High precision

Focus Repeatability (Precision)

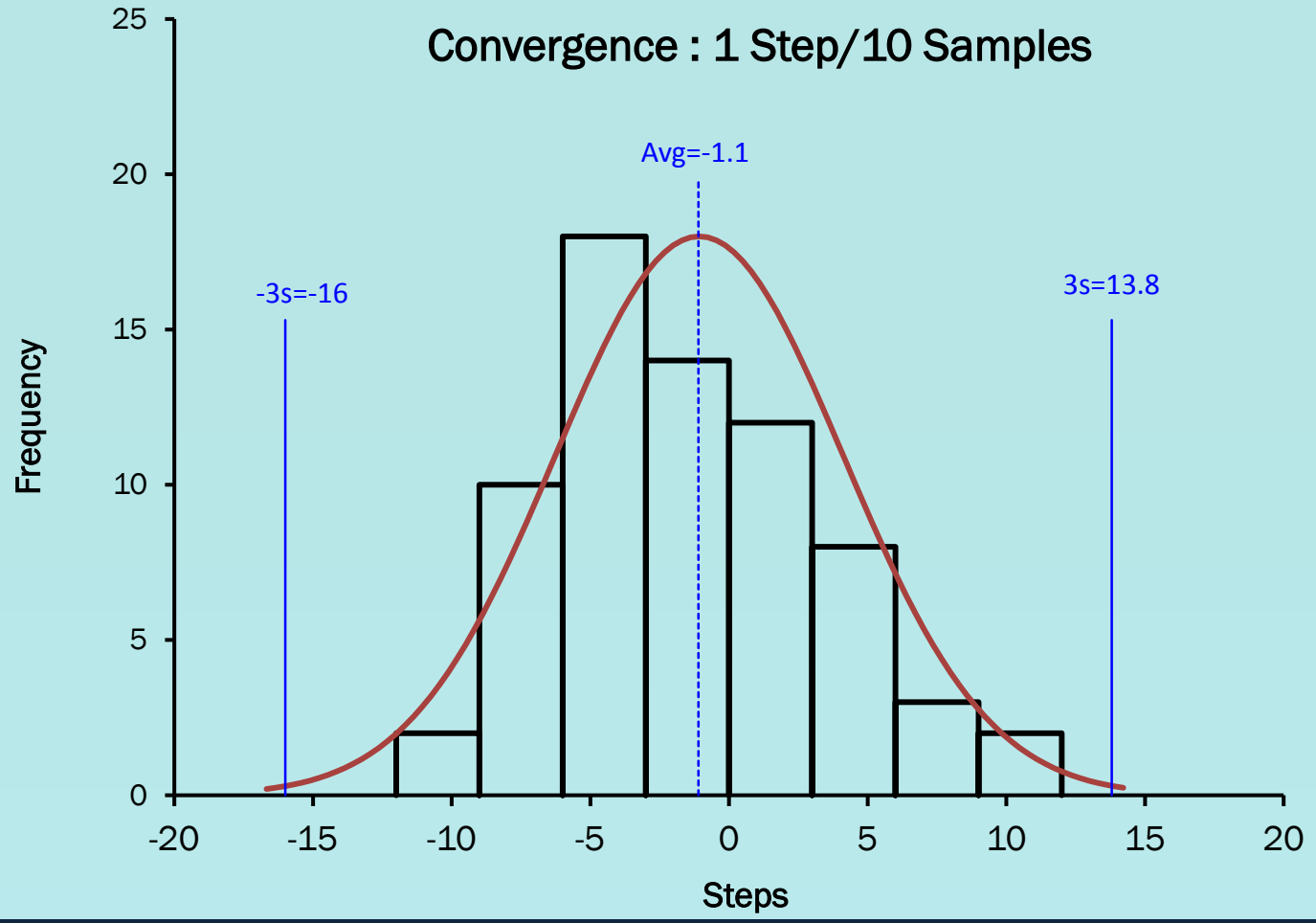
FocusMax

Time	Temp	Position	HFD	Delta (steps)
4.50.55	4.5	2571	3.59	
4.52.54	4.5	2574	3.66	-3
4.55.26	4.5	2573	3.66	1
5.04.10	4.5	2573	3.7	0
5.10.09	4.5	2567	3.76	6
5.13.11	4.5	2565	3.77	-2
5.17.25	4.5	2571	3.99	-6
5.19.27	4.5	2569	4.08	2

Precision (error)

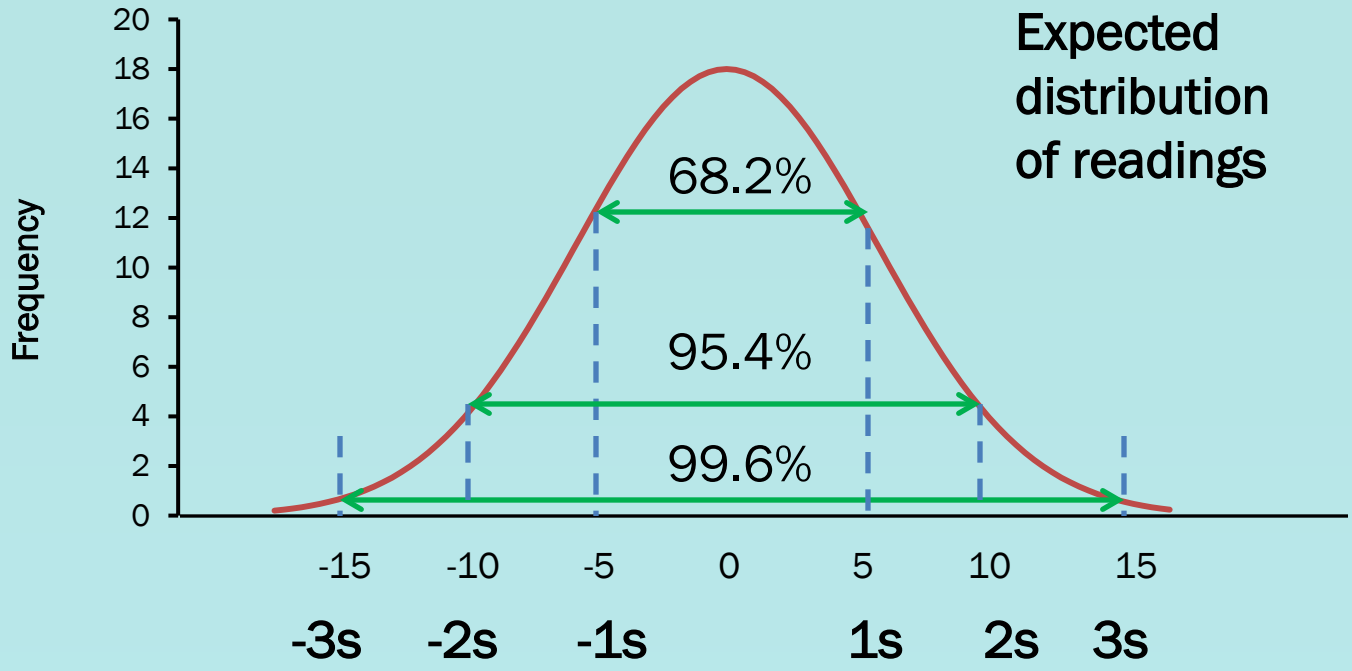
FocusMax

Focus Repeatability



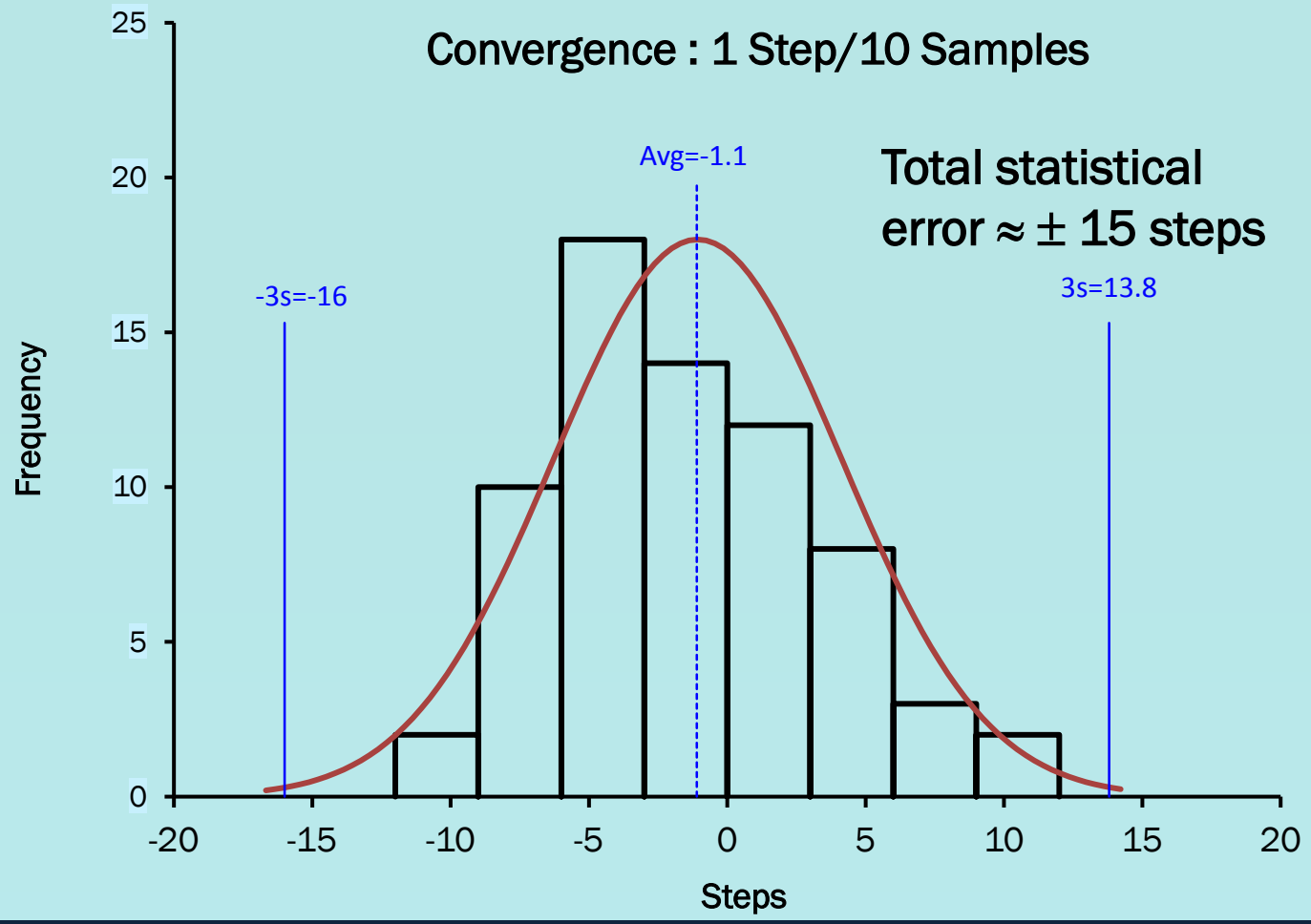
FocusMax

Focus Repeatability



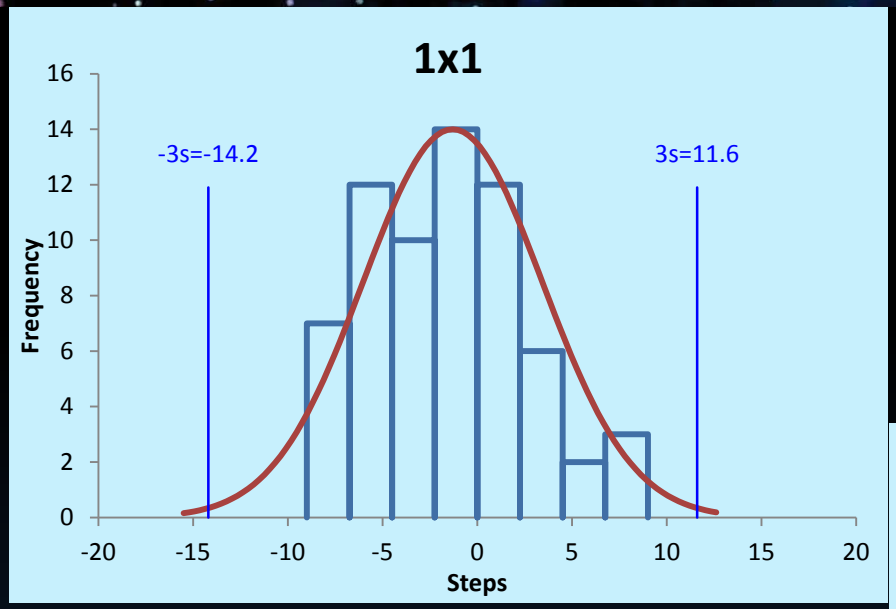
FocusMax

Focus Repeatability

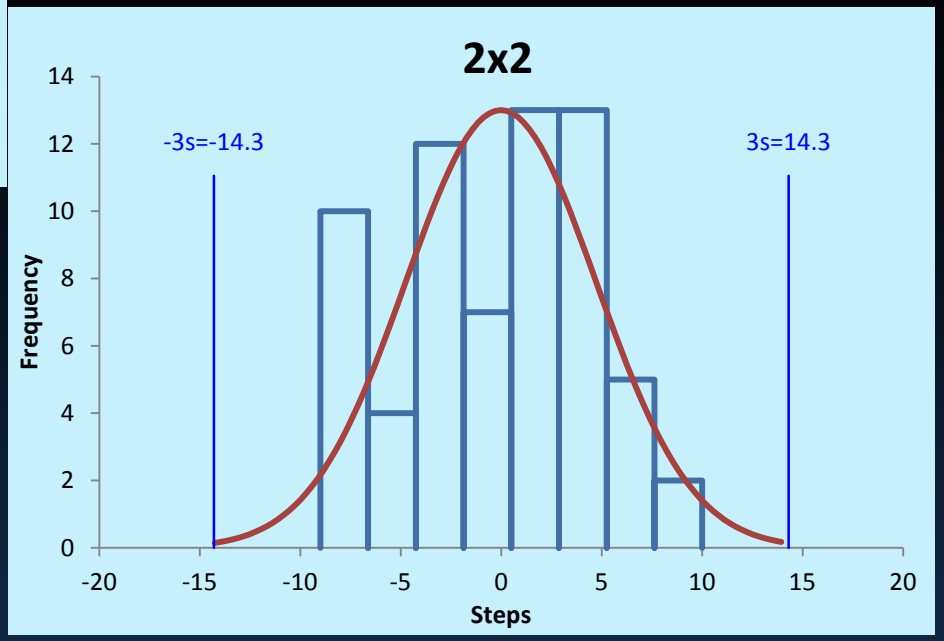


FocusMax

Focus Repeatability

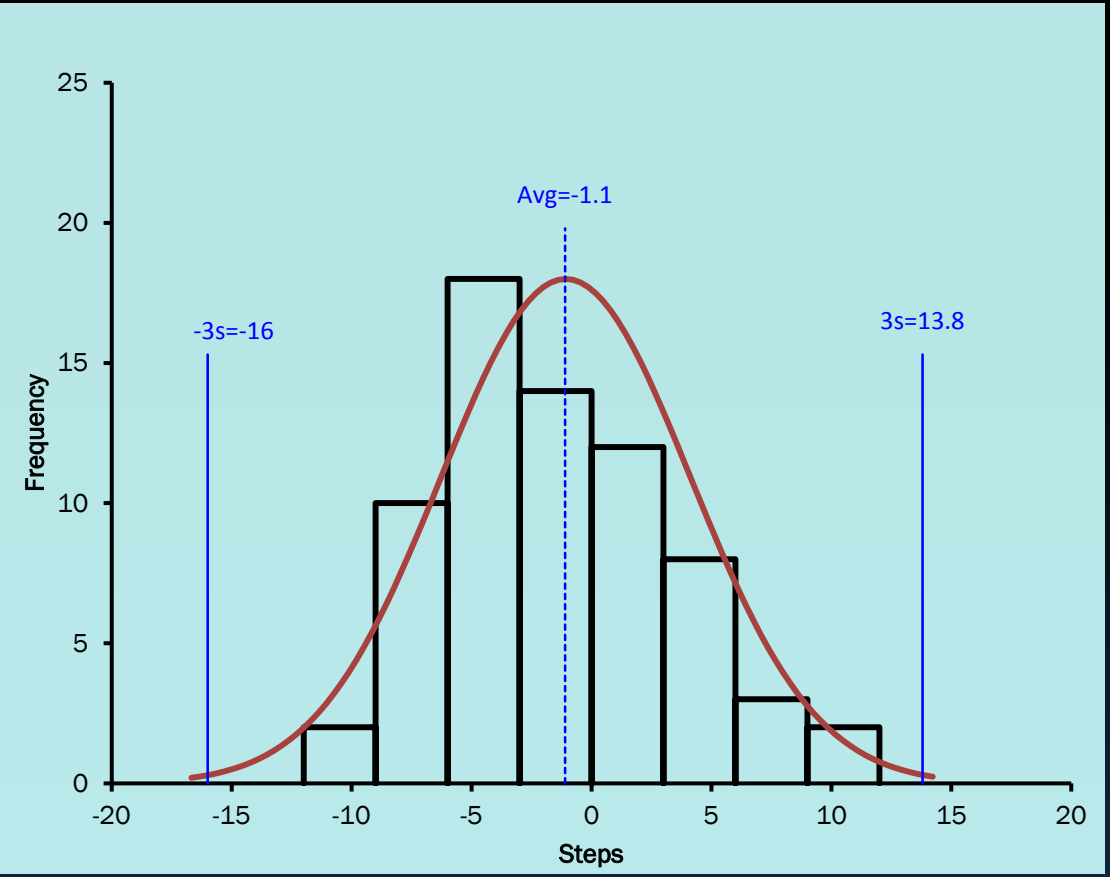


No significant difference with binning



FocusMax

Focus Repeatability



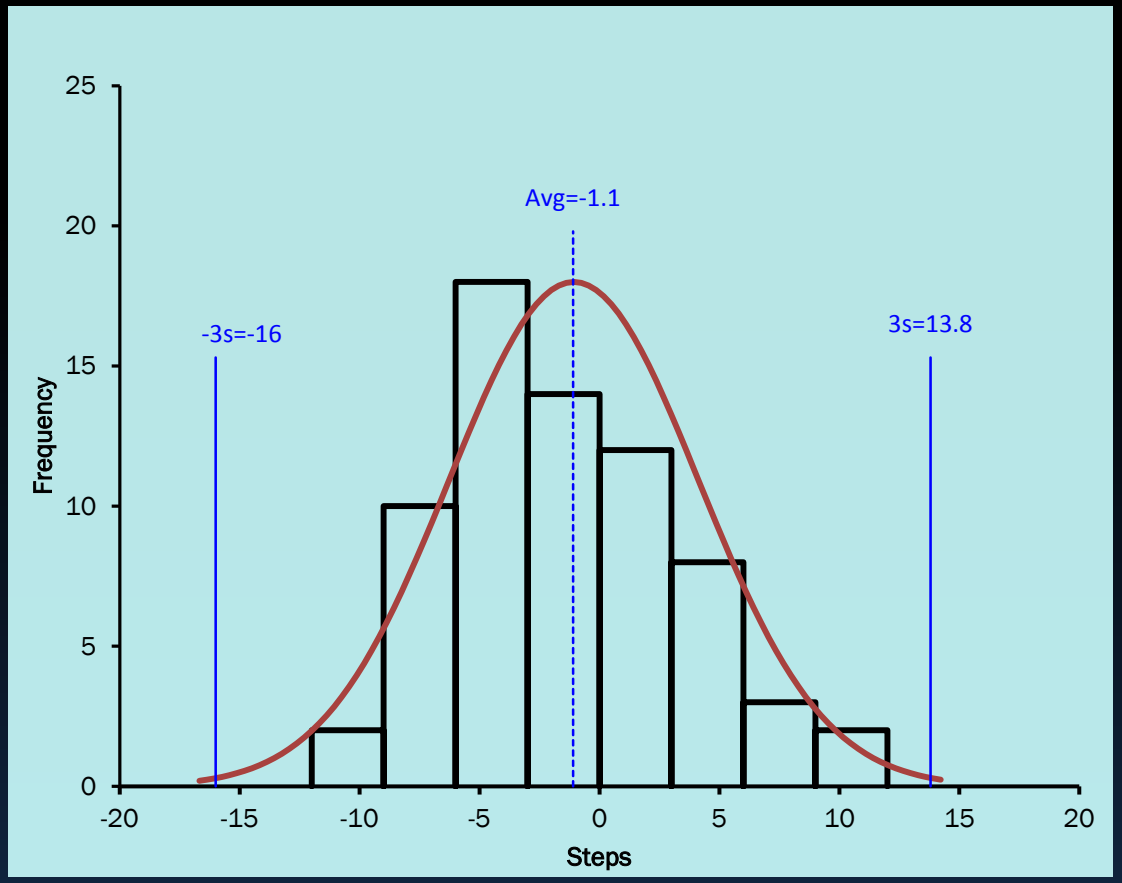
16" F/4.5 Newtonian
Optec focuser

1 step = 2.18μ

Total error = ± 15 x 2.18
= ± 33 μ
= ± .0013”

FocusMax

Focus Repeatability



Is ± 33μ error good or bad??

16" F/4.5 Newtonian
Optec focuser

1 step = 2.18μ

Total error = ± 15 x 2.18
= ± 33 μ
= ± .0013”

FocusMax

Critical Focus Zone and "New" Critical Focus Zone **

$$CFZ = 4.88 * F^2 * \lambda = 49\ \mu$$

$$NCFZ = 1.6 * F^2 * \lambda = 16\ \mu$$

** Get Focused!
D. Goldman & B. Megdal
Jan, 2010

FocusMax

Critical Focus Zone and "New" Critical Focus Zone **

CFZ = 4.88 * F^2 * λ = 49 µ

NCFZ = 1.6 * F^2 * λ = 16 µ

My focus precision > CFZ & NCFZ

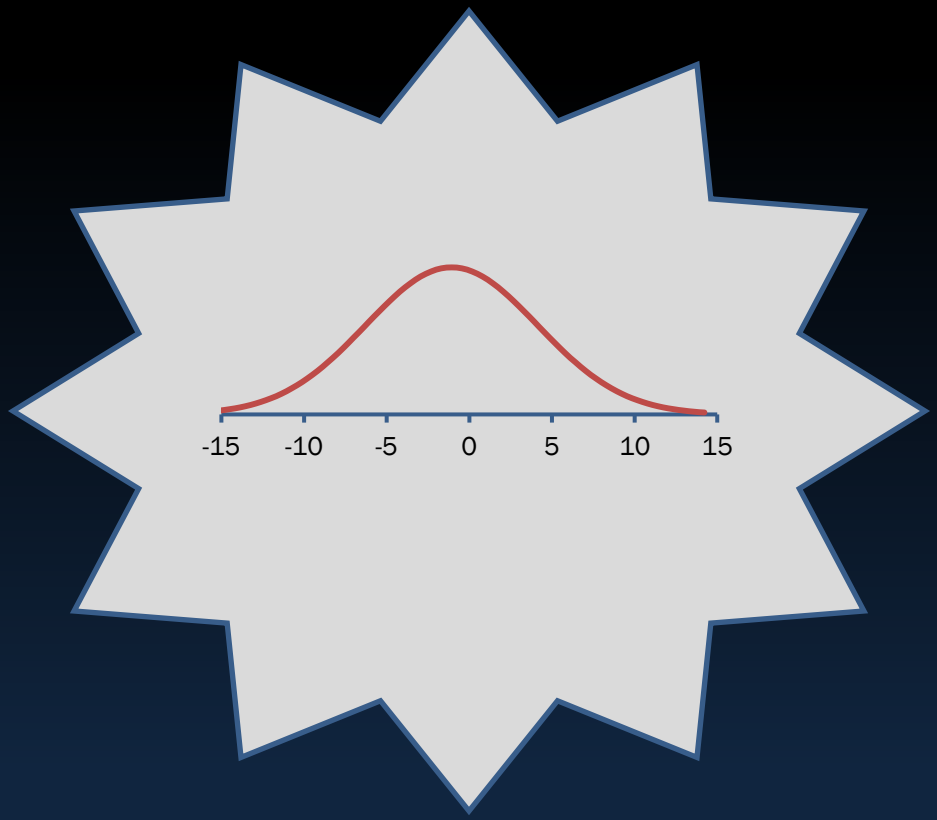
CFZ & NCFZ does not take into account:

- Seeing
- Telescope aperture

FocusMax

Focus Repeatability

What is the positional error of
± 15 steps as a percent of seeing ?



"New Critical Focus Zone" **

Takes into account:

- Seeing
- Telescope aperture
- Telescope focal ratio
- Acceptable focus tolerance

** Dr. Jeff Winter
http://www.goldastro.com/goldfocus/ncfz.php

"New Critical Focus Zone"

$$NCFZ = 0.00225 \cdot \theta_{FWHM} \cdot \sqrt{\tau \cdot A \cdot f^2}$$

NCFZ (microns)
0.00225 - constant (microns per arc-sec/mm)
θ_{FWHM} - total seeing (arc-sec)
τ - focus tolerance as a percentage of total seeing (no units)
A - telescope aperture (mm)
f - effective imaging system f/ratio (no units)

FocusMax

"New Critical Focus Zone"

My 16" Newtonian:

θ_{FWHM} = 3.0" (my typical seeing)

τ = ??

A = 16" x 25.4 = 406.4mm

f = 4.5

NCFZ = 66μ *total focus repeatability error*

$$T = \left(\frac{66\mu}{.00225 \times 3 \times 406.4 \times 4.5^2} \right)^2$$

= 1.4% focus error in 3" seeing

"New Critical Focus Zone"

3% focus error In 2" seeing

12% focus error in 1" seeing

BUT

I would expect much better focus repeatability (precision) in seeing better then 3 arc-sec!

FocusMax

Focusing System

- Good accuracy (center of CFZ)
- Good precision
  - Focuser step size should not be under sampled to CFZ
  - Under sampled means 1 focuser step >= CFZ

FocusMax

Focusing System

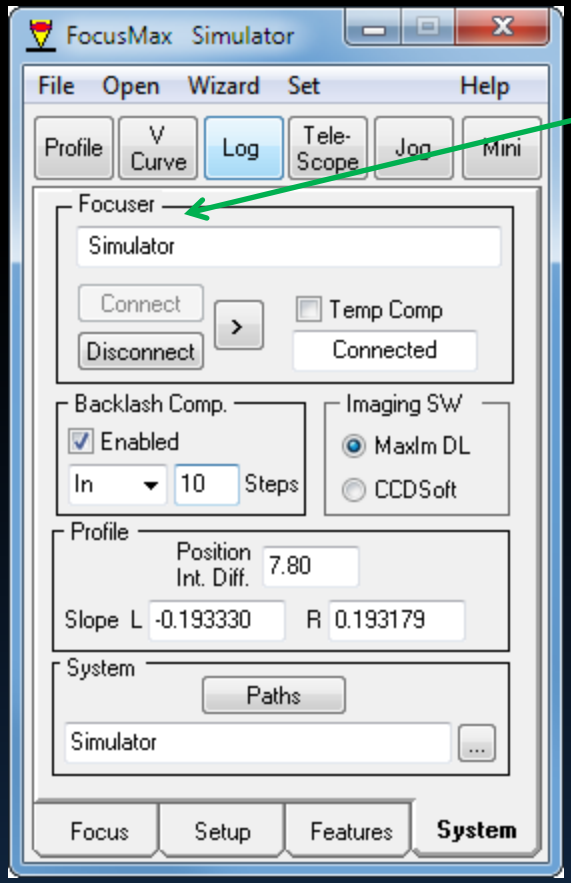
What should be the minimum
focuser step resolution relative to the CFZ ??

10:1 rule of thumb used in metrology

- “Measurements should be sensitive enough to detect differences as slight as one-tenth of the total tolerance “ (CFZ)
- “Inadequate discrimination will affect both accuracy and precision”

There is also a 4:1 rule but 10:1 has been universally adopted

Setup Tab

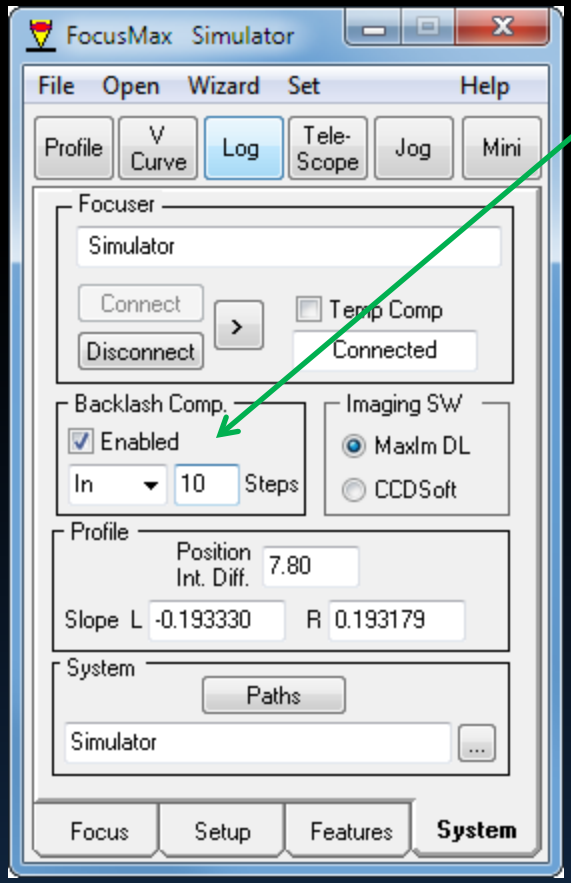


Focuser:

- Choose ASCOM Focuser
- Setup focuser
- Connect / Disconnect focuser
- Enable native focuser driver temperature compensation

FocusMax

Setup Tab



Backlash Compensation:

- Set focuser backlash direction In/Out
- Number of steps

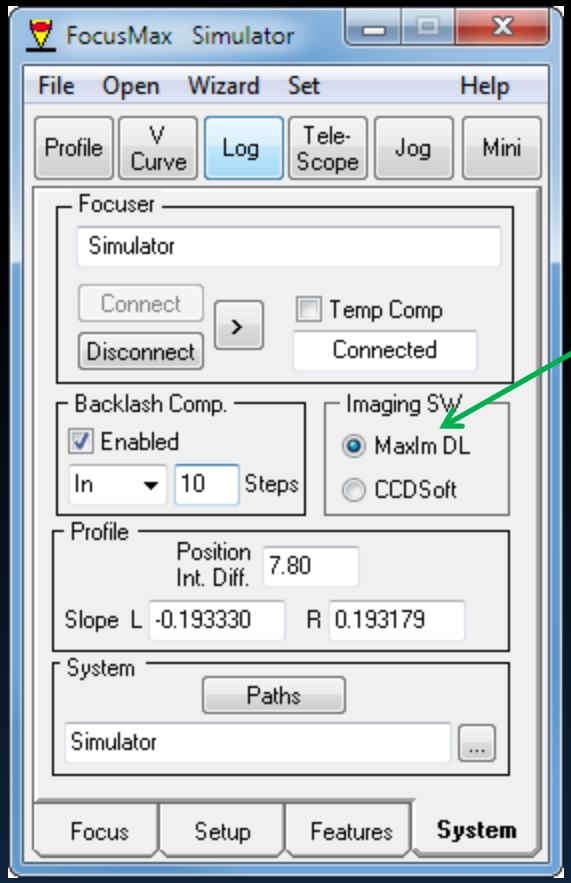
BL Setting may be available in focuser documentation

You can measure the actual backlash with a drop indicator

Older SCT telescopes may required up to 200 steps in cold temperatures

FocusMax

Setup Tab

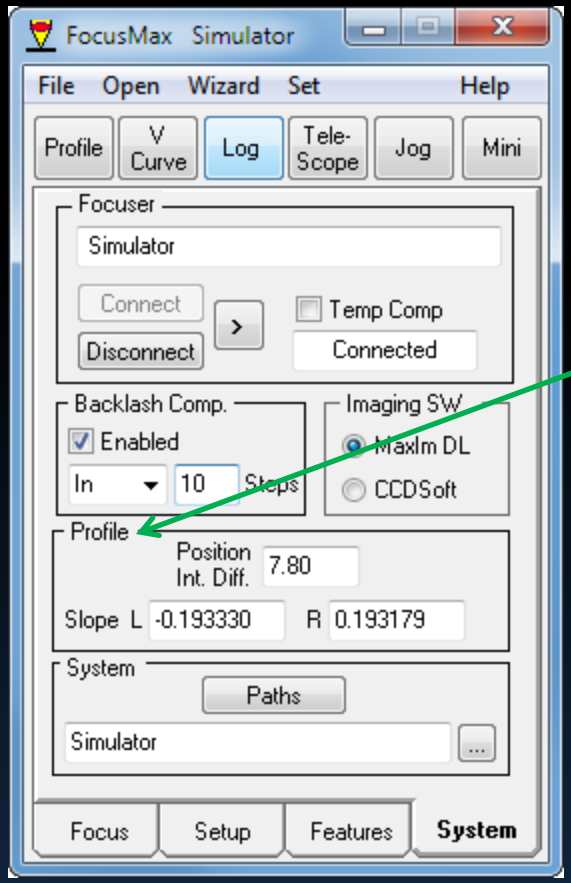


Imaging SW:

Select either MaxIm Or CCDSoft

FocusMax

Setup Tab

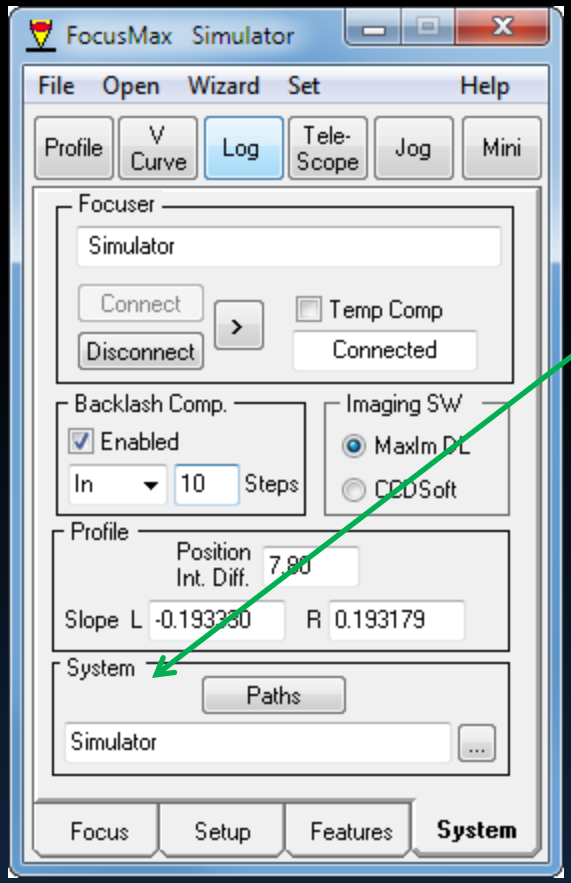


Profile:

Current Vcurve parameters (from Profile window)

FocusMax

Setup Tab

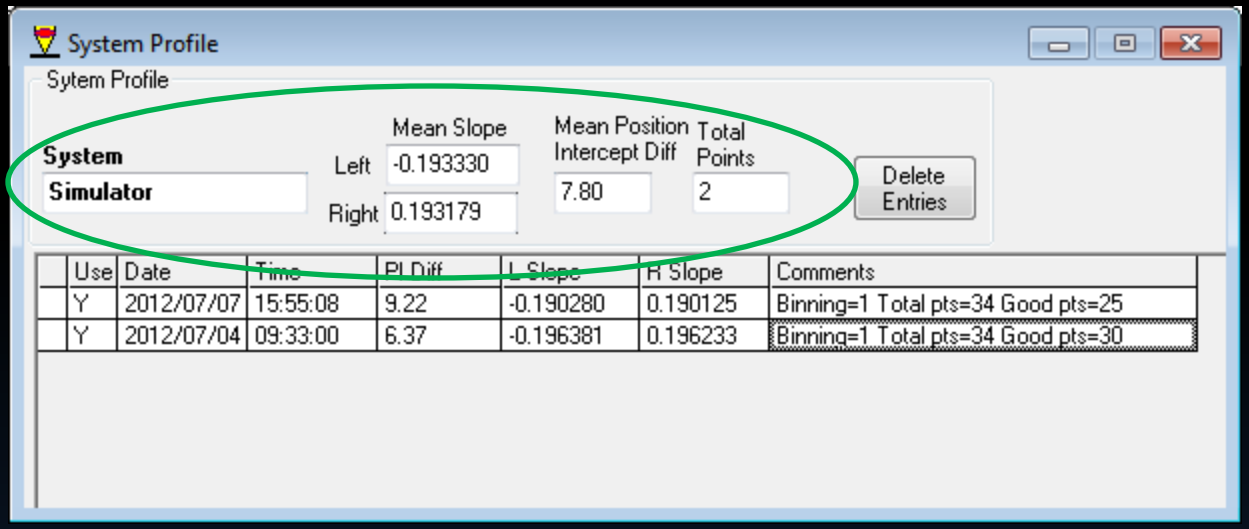


System:

- The current user selected system.ini file where data will be saved
- Paths button allows you to change the location of the Log files and Images

FocusMax

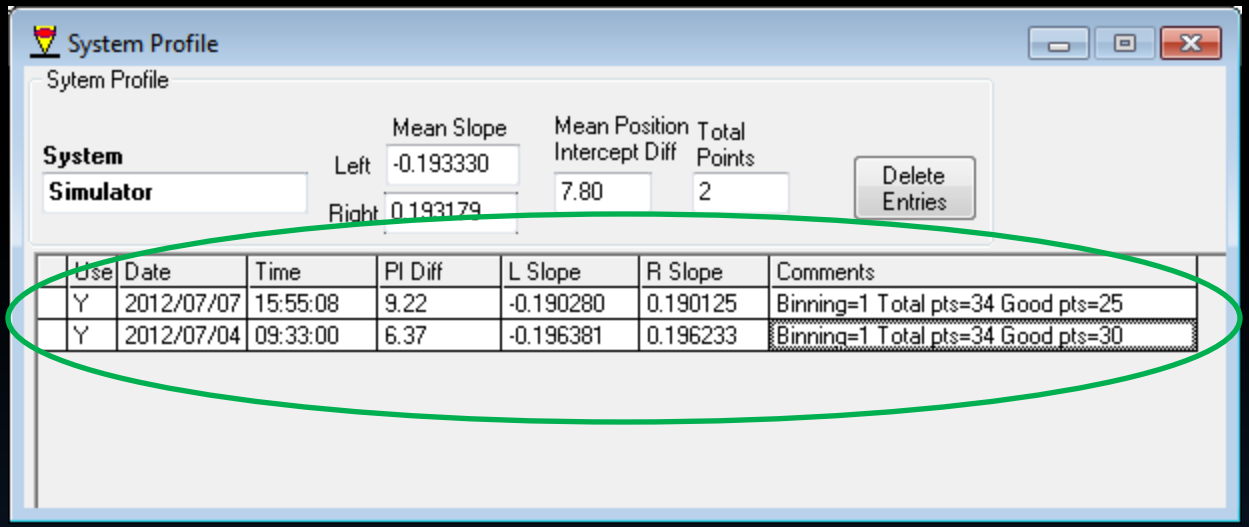
System Profile



Shows the average Left & Right Slopes and PID

FocusMax

System Profile

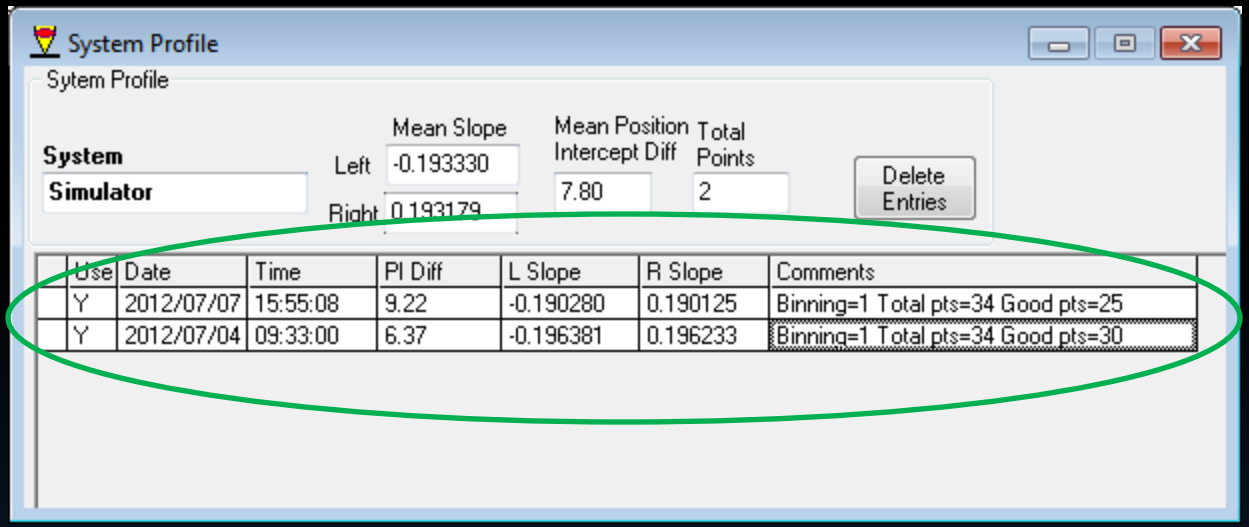


Vcurve run data

- Enable / Disable row
- Delete a row
- Binning, Total points and number of good points

FocusMax

System Profile

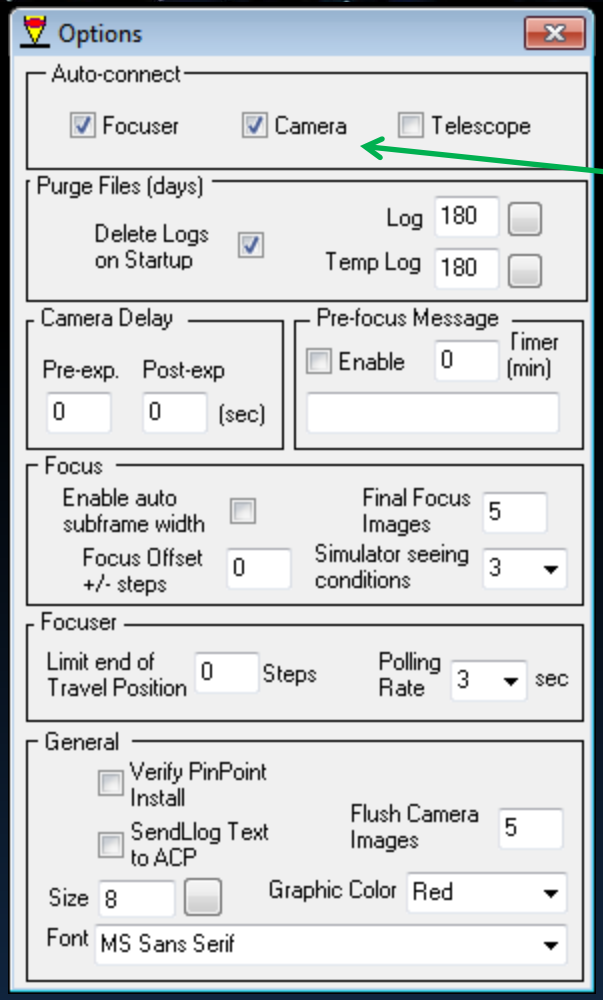


Vcurve run data:

1. Review Left & Right Slopes and PID
2. Delete values that look like fliers
3. Want ~ 12 good Vcurve rows in your Profile

FocusMax

Options



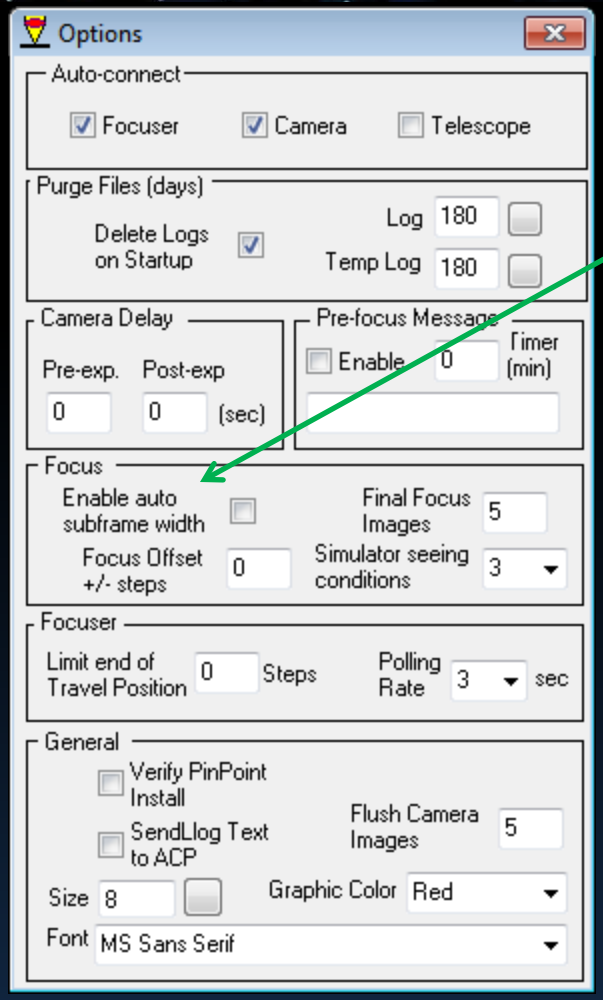
Auto-connect:

Connect devices on startup

- Focuser
- Camera
- Telescope

Default is none

Options

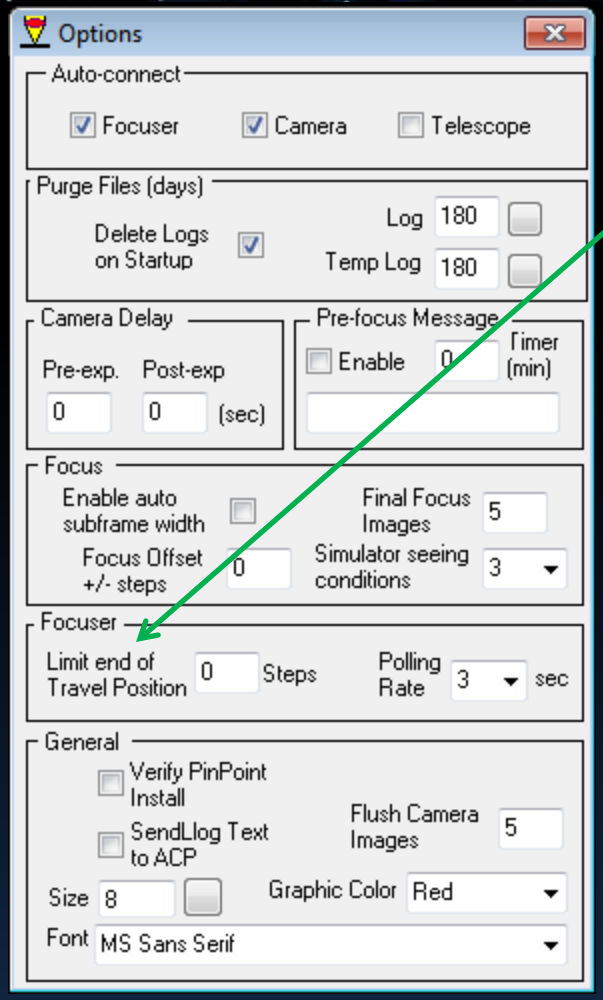


Focus:

- **Enable Auto Subframe Width** use subframe width defined on Setup Tab
- **Offset** - useful for photometry to defocus an image
- **Final Focus Images** - average the HFD of consecutive images when the focuser moves to the Best Focus position

FocusMax

Options



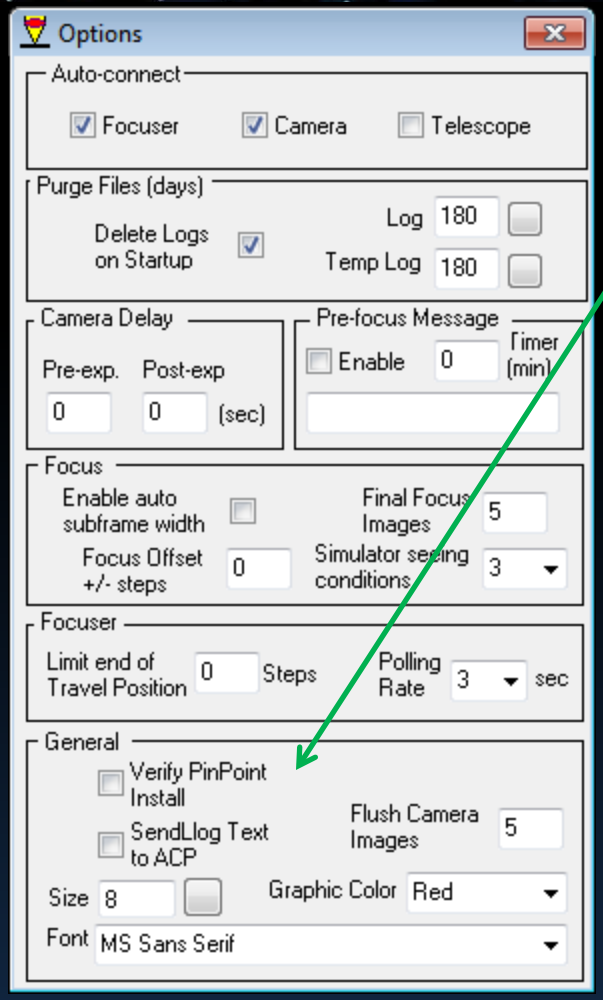
Focuser:

Limit End of Travel Position prevent the focuser from reaching physical hard stop

Polling Rate - set the time (sec) that the focuser is polled for temperature and position information

FocusMax

Options

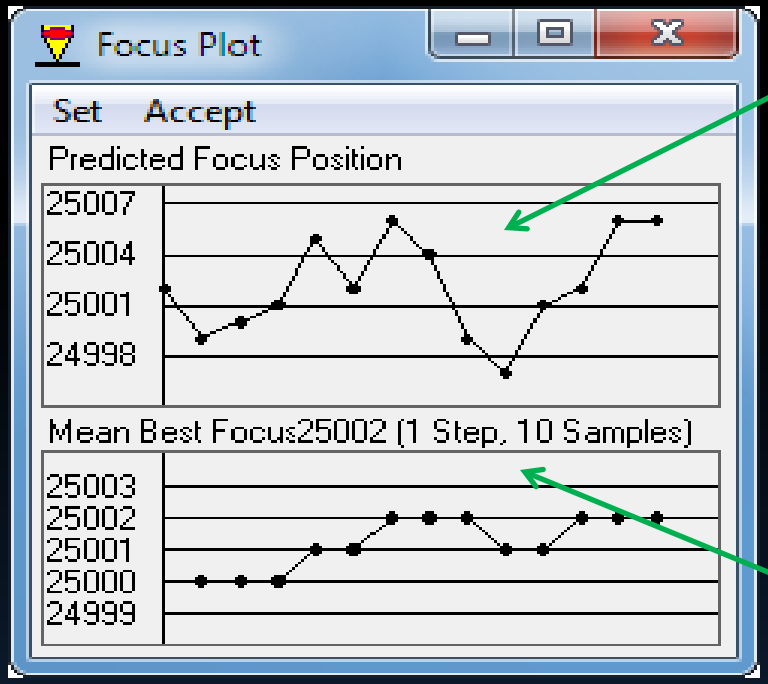


General:

- **Flush Camera Images** - consecutive 0 sec exposures at the end of the autofocus run to remove potential ghost image on the next image
- **Font and Font Size** can be set
- **Graphic Colors** Red, Green, Blue – useful for laptops with red mylar

FocusMax

Focus Plot



Predicted Focus Position for each subframe image – note variation in position from each image due to seeing

Mean Best Focus - the average focus position

FocusMax

FirstLight Wizard

- Handles limited range focusers
  - FLI
  - Optec
  - focal reducer
- Gracefully handles sins of relative focusers
  - Backlash
  - End of mechanical travel
- Finds lost stars
- Accurately sets up Vcurve range values

FocusMax

FirstLight Wizard

- Manually focus the telescope
- Make mechanical adjustments so that the focus position is mid-way between the In and Out travel of the focuser
- Select a star near the zenith, press the Find button and verify in the Log that the resulting Min/Max Flux falls within the boundary on the Setup tab
- Verify that the star is not saturated

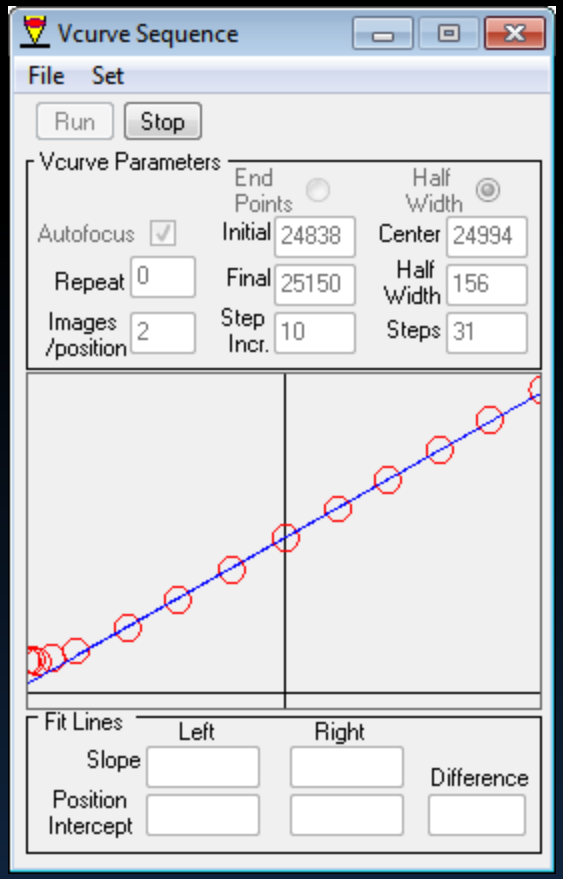
FocusMax

FirstLight Wizard

- Select the First Light Wizard from the Wizard menu
- The wizard will prompt you at each step of the process

FocusMax

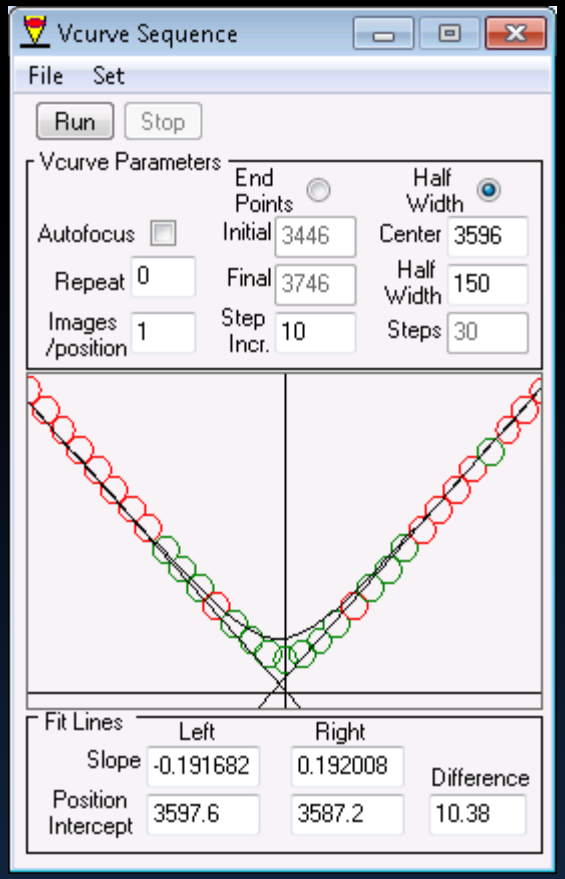
FirstLight Wizard



- Wizard will start by moving the focuser away from the focus point to estimate the slope of one side of the ‘Vcurve’
- Will continue to move the focuser until it achieves the HFD setting (default = 40)
- If your focuser can not achieve this setting then re-run the First Light Wizard and reduce the HFD value when prompted

FocusMax

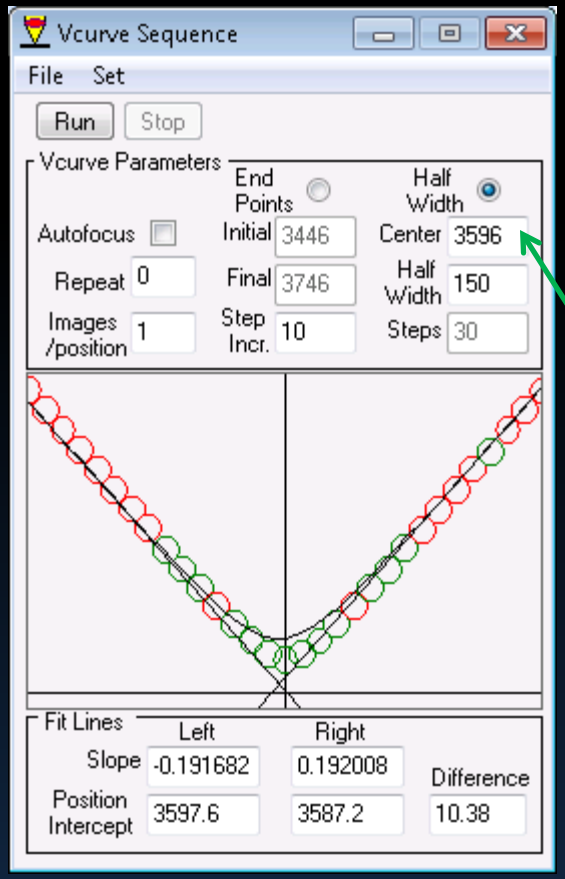
FirstLight Wizard



- Once the slope has been estimated, the Vcurve is generated
- Vcurve results are saved in system Profile

FocusMax

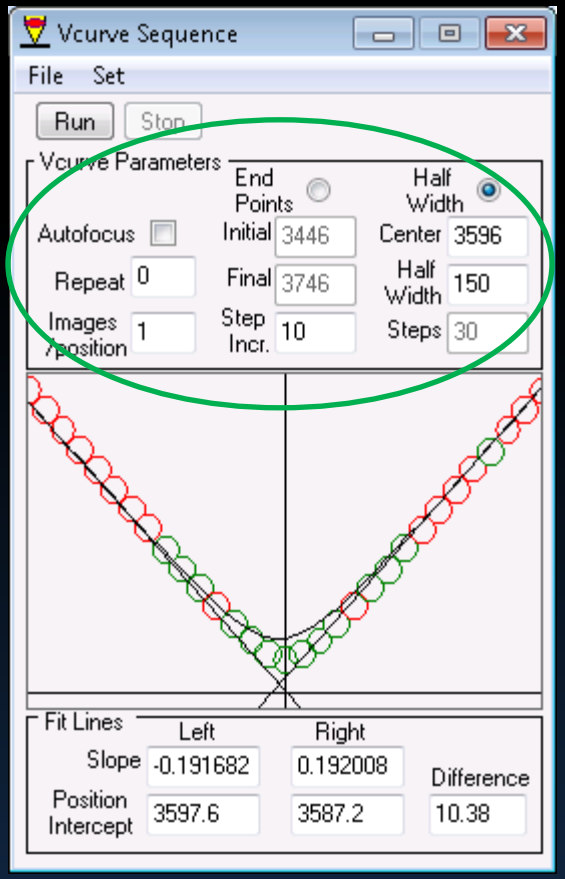
Manual Vcurve



1) Focus the telescope
2) Adjust focuser to midpoint of focuser travel
3) Select 4 – 6th mag star (fainter for larger apertures) near zenith
4) Open Vcurve window - current focuser position will be entered

FocusMax

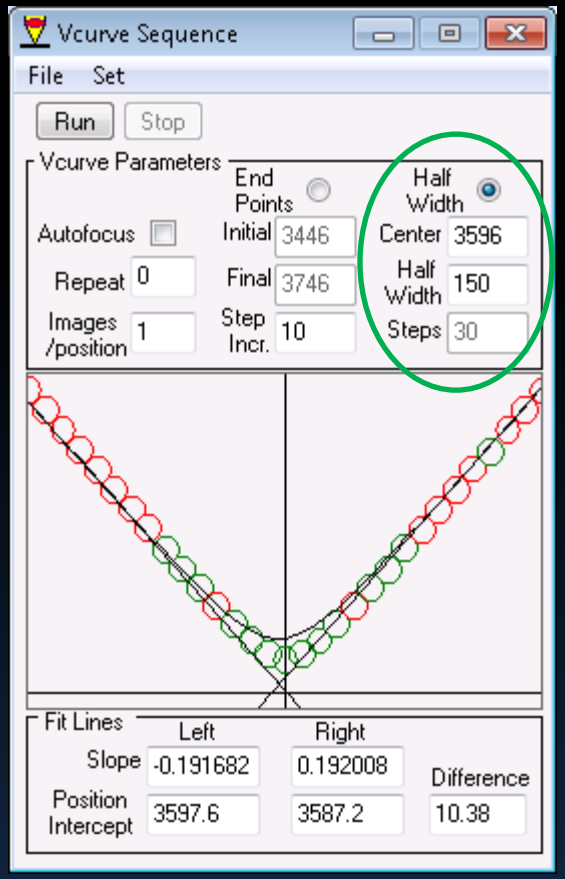
Manual Vcurve



- Half Width - number steps away from focus
- End Points - initial and final focuser positions
- Step Increment - number of steps the focuser will move
- Steps - number of moves that will be made
- Repeat - rerun the Vcurve
- Images/position - take multiple images and average the HFD at each move (helps with seeing effects)

FocusMax

Manual Vcurve

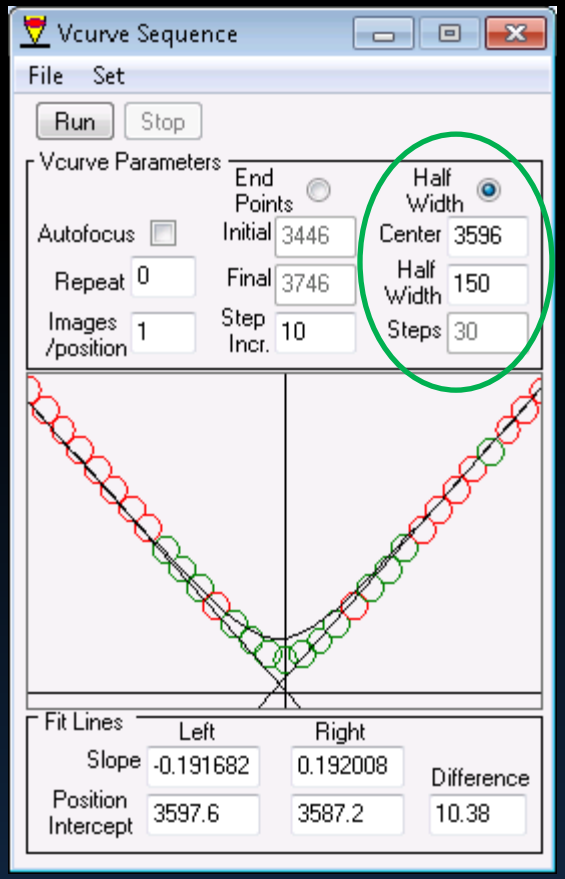


Method #1 - Half Width:

1) Manually focus the telescope
2) Press the Jog button and move the focuser In or Out 100 units then press the Find button
3) Continue to move the focuser until you achieve an HFD of 20+ (30 - 40 is better)
4) Note the focuser position
5) Bring the focuser back to the focus position and press the Half Width button on the Vcurve window
6) Enter the difference between the focus position and the position achieved when you manually jogged the focuser
7) Press Run

FocusMax

Manual Vcurve

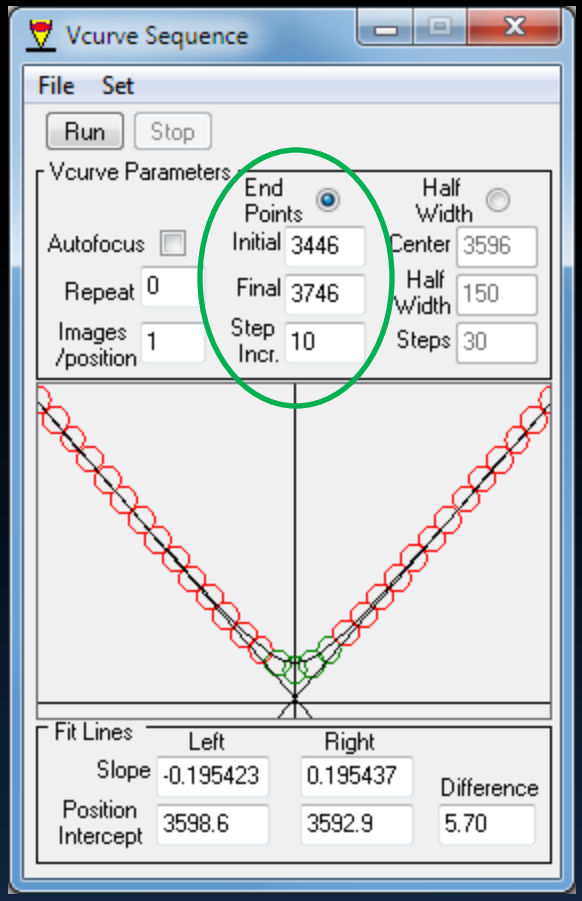


Method #1 Example:

1) Focus position is 3,500 and 4,000 was the position to achieve 30 HFD
2) Enter the difference of 500 into the Half Width box
3) Adjust the Step Increment value until you see 30 - 40 Steps displayed
4) Press Run

FocusMax

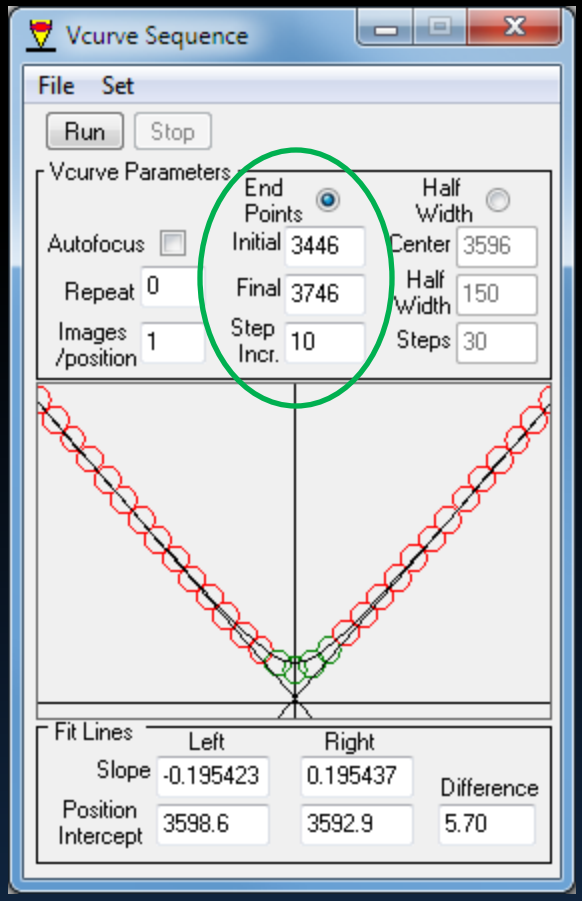
Manual Vcurve



Method #2 - End Points:

1) Press the End Points button on the Vcurve window
2) Press the Jog button and move the focuser 'Out' 100 units then press the Find button
3) Continue to move the focuser until you achieve an HFD of 20+ (30 - 40 is better)
4) Enter the focuser position in the Initial position

Manual Vcurve

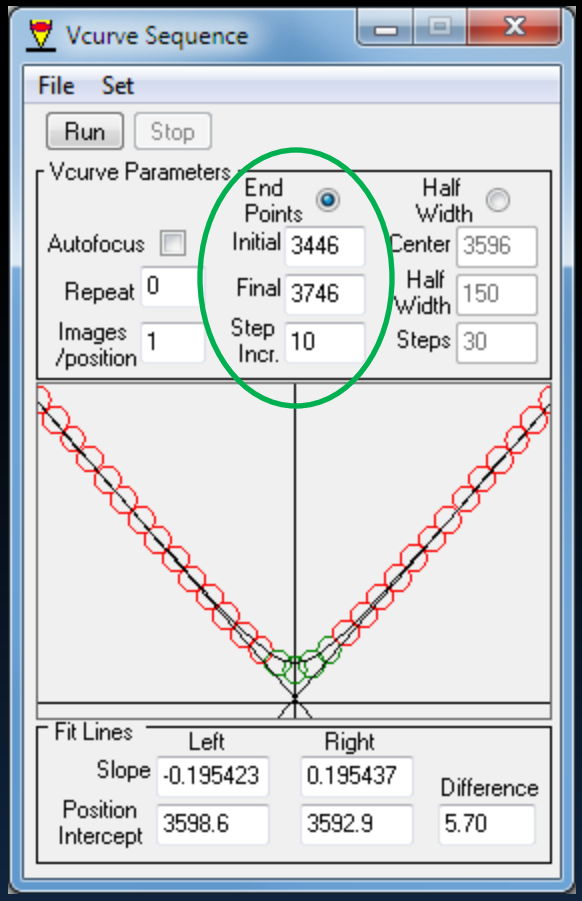


Method #2 - End Points:

5) Move the focuser 200 units 'In' then press the Find button
6) Continue to move the focuser until you find the position approximately equal to the HFD from step 3
7) Enter the focuser position in the Final position
8) Bring the focuser back to the focus position
9) Press Run

FocusMax

Manual Vcurve



Method #2 - Example:

1) Focus position is 3,596
2) Initial position = 3446 (In) to achieve 30 HFD
3) Final position = 3746 (Out) to achieve 30 HFD
4) Adjust the Step Increment value until you see 30 – 40 Steps displayed
5) Press Run

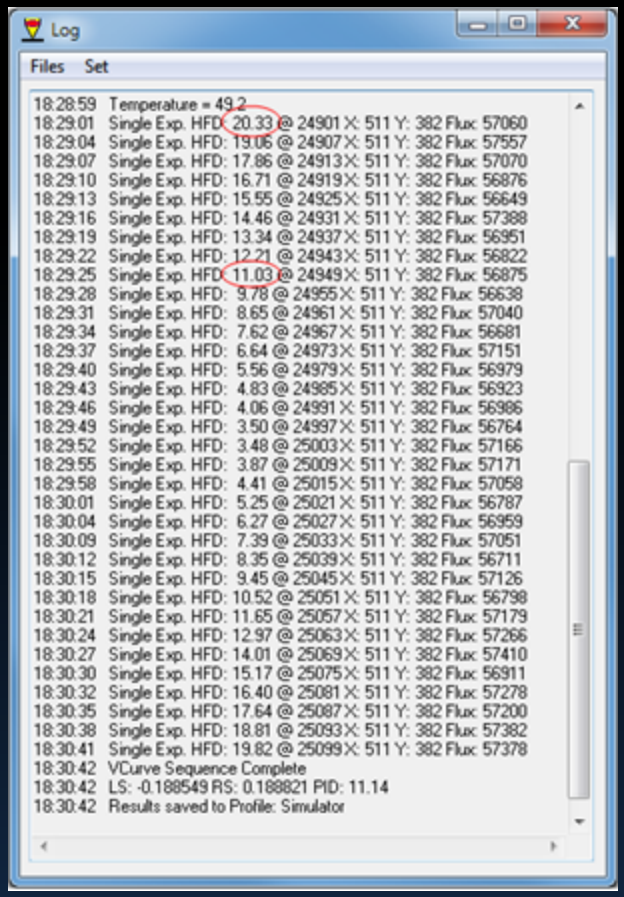
How are Slopes Determined?

Hyperbola fit to Vcurve

- Line fit is tangent to hyperbola (‘wings’)
- Gives better fit statistic
  - uses both sides of V Curve for fit
  - rejects deviant points due to seeing
- Rejects flat spots due to
  - focuser backlash
  - focuser mechanical end of travel

FocusMax

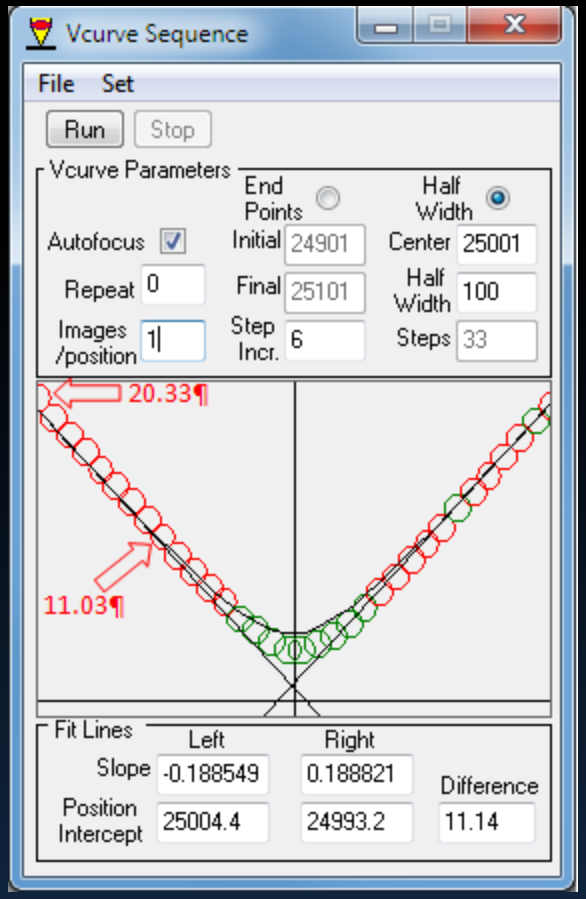
Setting Focus Start and Near Focus HFD (Setup Tab)



1) Generate a Vcurve
2) From the Log identify the right or left most extreme HFD value (20.33)

FocusMax

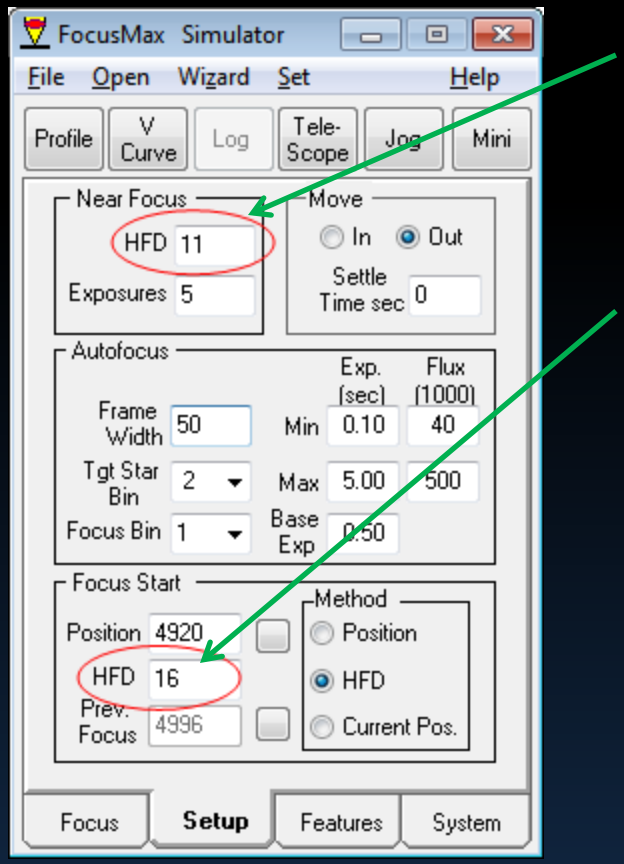
Focus Start and Near Focus HFD Settings (Setup Tab)



3) Examine the Vcurve graph and identify the circle which begins to deviate from a straight line
4) Determine HFD value in the Log by counting down to the circle number from step 2

FocusMax

Focus Start and Near Focus HFD Settings (Setup Tab)

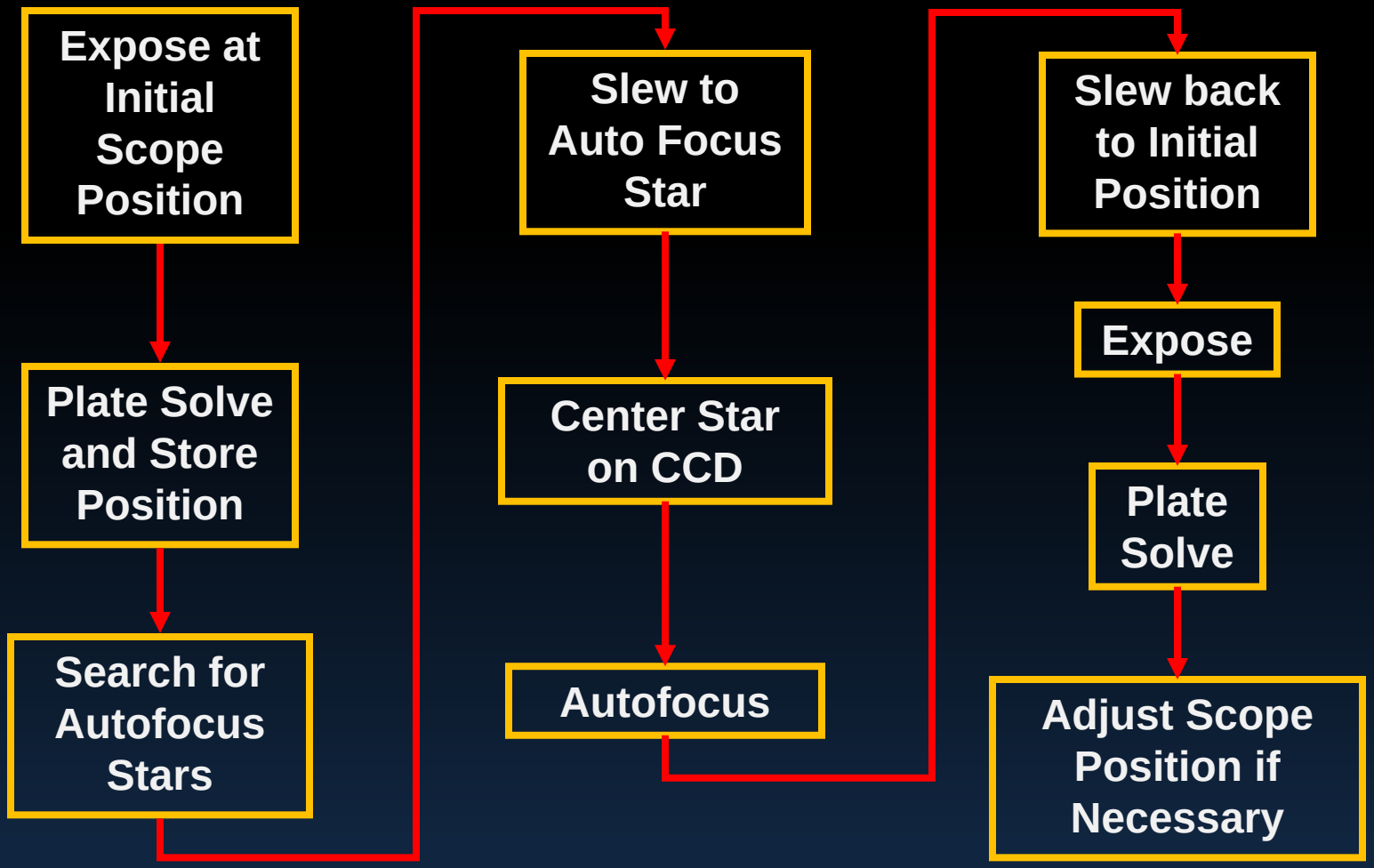


5) Round off the HFD value and enter the value in the Near Focus (11)

6) Enter the Focus Start HFD some 5 units higher than the Near Focus HFD (16)

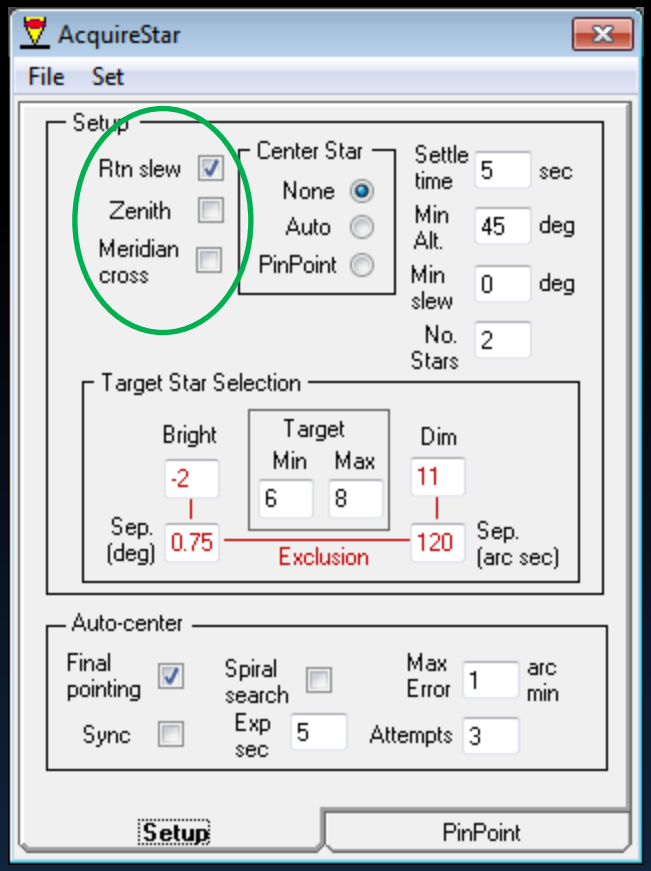
FocusMax

Acquire Star



FocusMax

AcquireStar

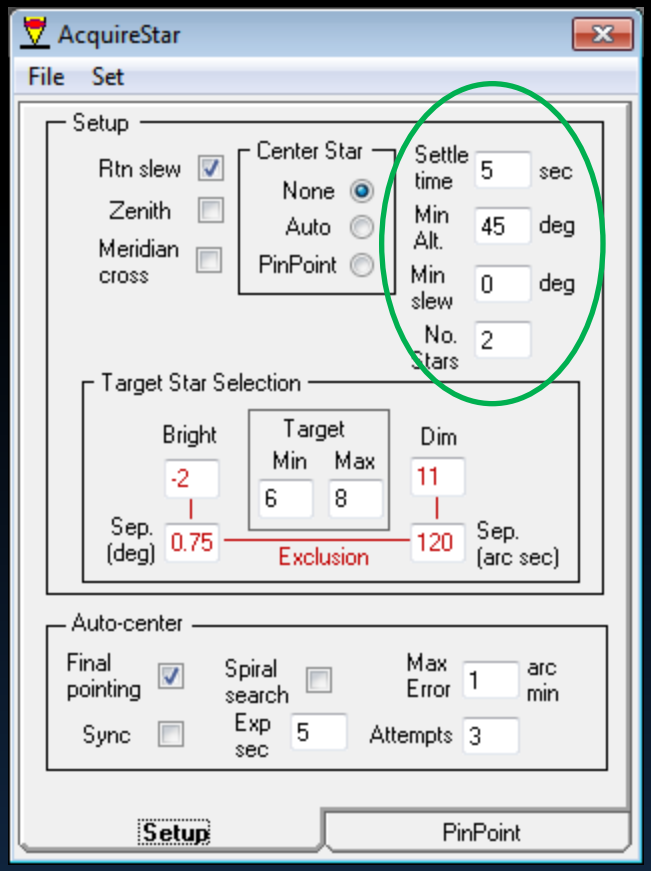


Setup:

- Return Slew after autofocus run
- Zenith – select stars from catalog starting at zenith
- Meridian Cross- do not check for most German Equatorial mounts

FocusMax

AcquireStar

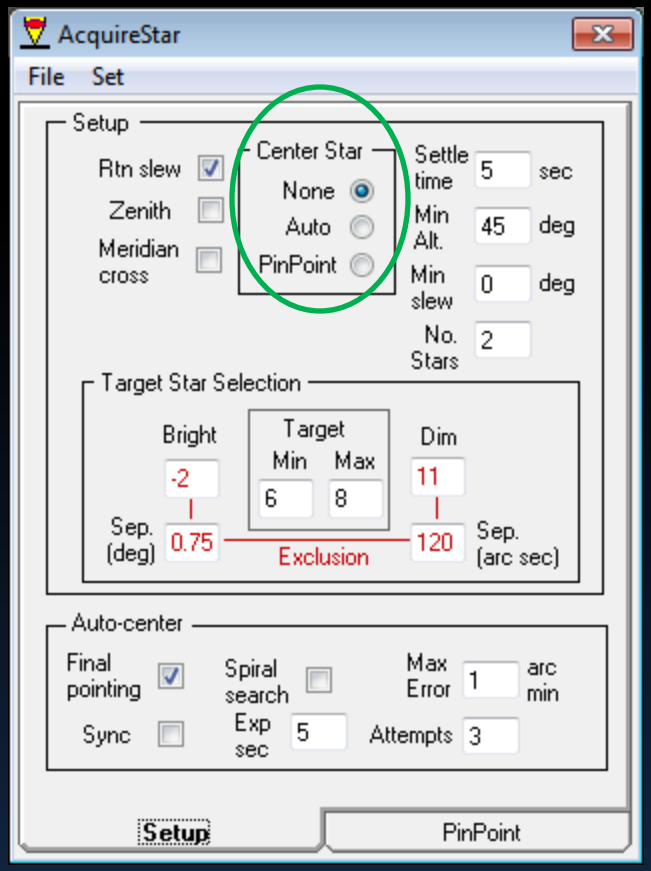


Setup:

- **Settle Time** after slew
- **Min Altitude** allowed for star
- **Min Slew** - set to 0 to use potential star in current FOV
- **Number of Stars** to select from catalog

FocusMax

AcquireStar



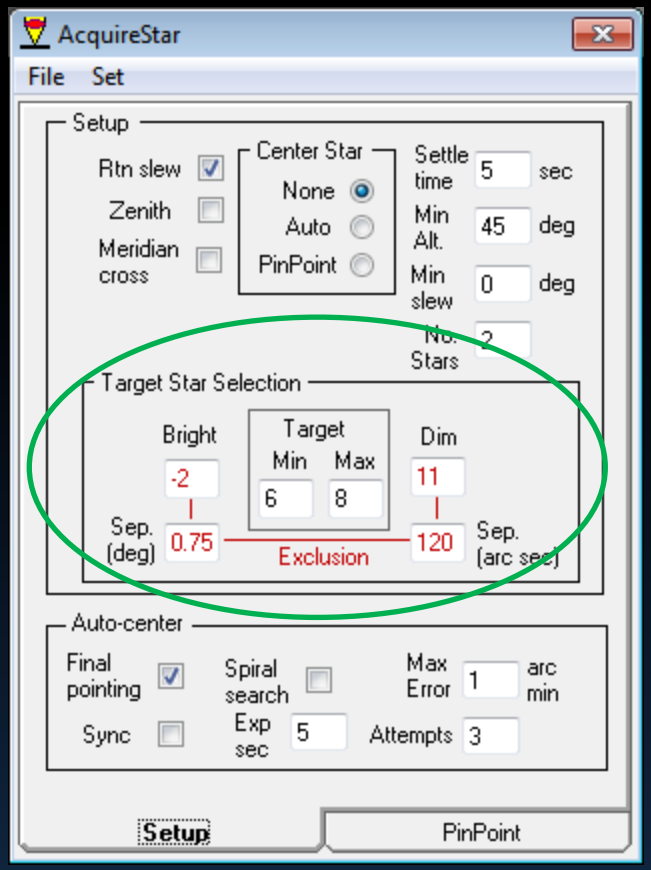
Setup:

Center Star

- **None** – blind slew to target star
- **Auto** – center star using calibrated telescope moves (see Telescope window to calibrate)
- **PinPoint** – center star with plate solved images with PinPoint

FocusMax

AcquireStar

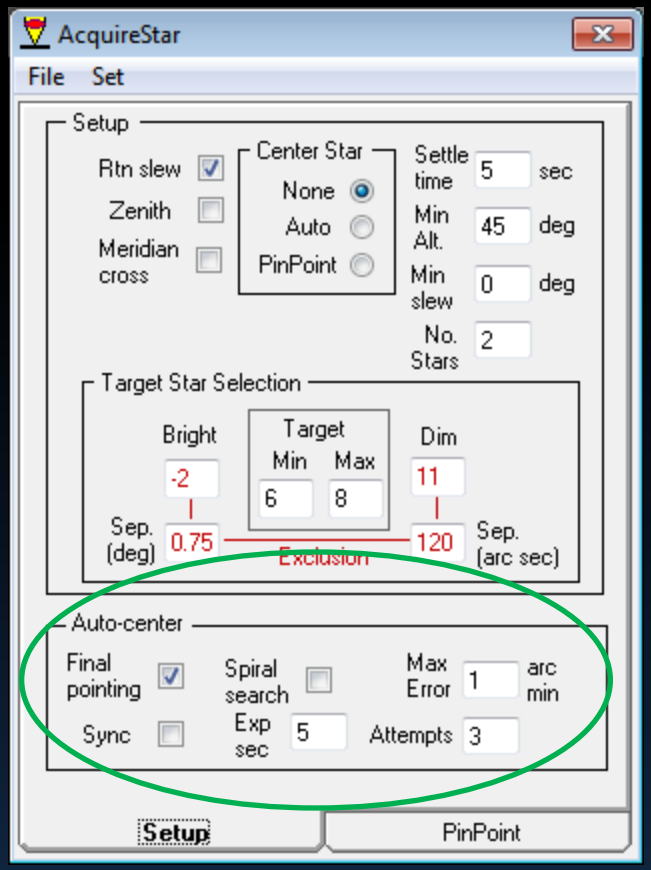


Target Star Selection:

- **Target Min/Max** – target star magnitude range to select from star catalog
- **Bright / Sep (deg)** – reject bright stars that are within 0.75 deg of potential target star.
- **Dim / Sep (arc sec)** - reject dim stars down to 11th mag that are within 120 arc-sec of a potential target star

FocusMax

AcquireStar

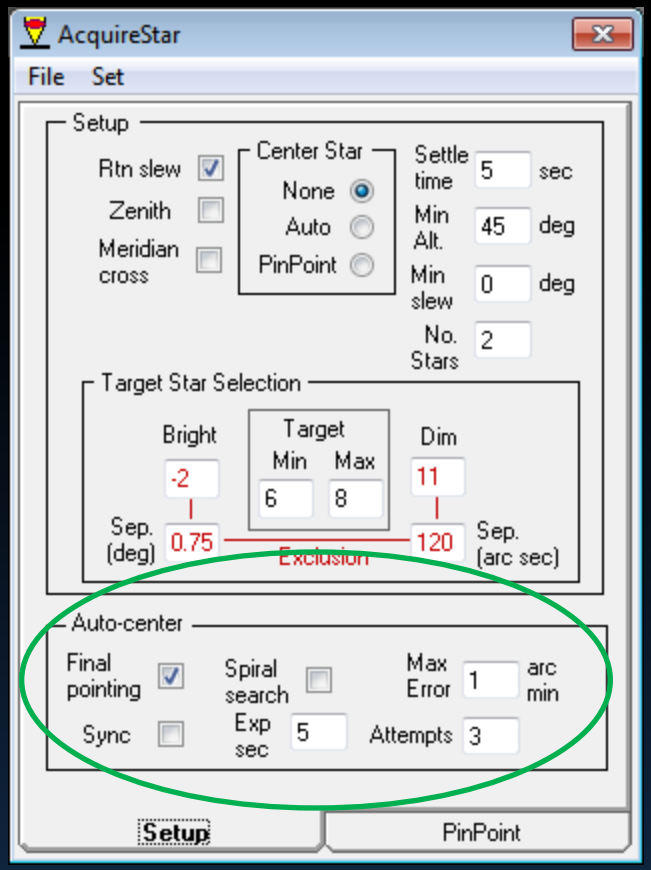


Auto-center:

- **Final Pointing** – fine tune telescope pointing after slew
- **Sync** telescope after successful plate solve with PinPoint
- **Spiral Search** to determine telescope pointing – useful if target is not on chip

FocusMax

AcquireStar



Auto-center:

- **Exposure** time for plate solving telescope pointing
- **Max Error** allowed on telescope slews. Will allow for < 1 arc-sec positioning if mount is able to make small accurate adjustments
- **Attempts** - the number of centering failures before declaring failure and telescope moves to next target star

FocusMax

AcquireStar

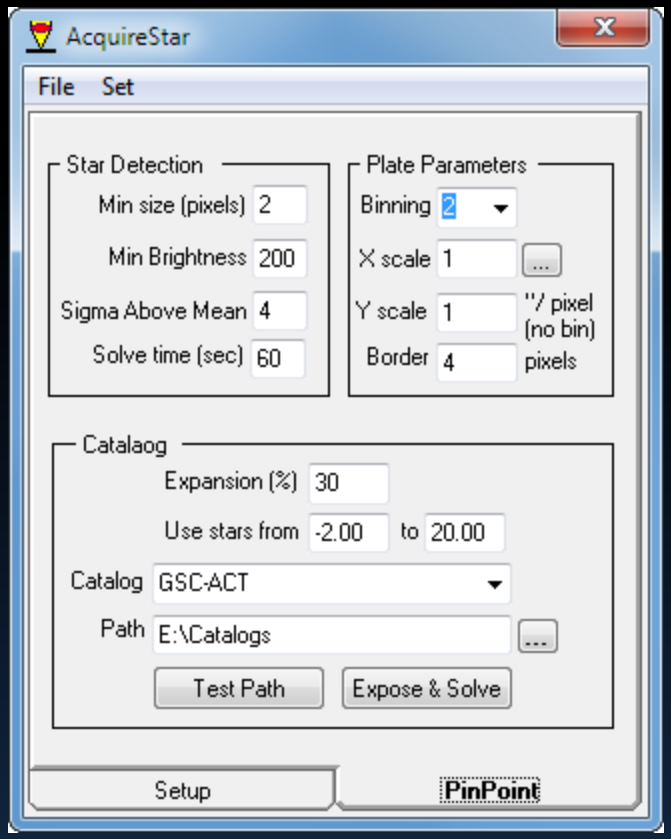


Plate Parameters:

- **Binning** for plate solves (1 – 4 allowed)
- **X & Y pixel scale** (at 1x1 binning)

Catalog:

- Select catalog and catalog path
- **Test Path button** will determine if PinPoint can read selected catalog at RA 00:00:00 Dec 00:00:00
- **Expose and Solve button** – take an actual image and plate solve

Temperature Compensation

- Maybe ‘black magic’
- May not work with all optical systems
- Some users report non-linear response (APO)
- Focuser should have a remote temperature probe
- Probe should be coupled to telescope – preferably near primary optics
- Avoid taking measurements until telescope has acclimated to ambient temp
- Most telescopes will require moving focuser out as temp drops (tube shrinkage)

FocusMax

Temperature Compensation

My 16” f/4.5 Newtonian

- Optec focuser with external probe
- Drilled hole in side of tube and positioned probe next to mirror face
- Measured Temperature vs. Position over multiple nights with Temp Comp Wizard

FocusMax

Temperature Compensation

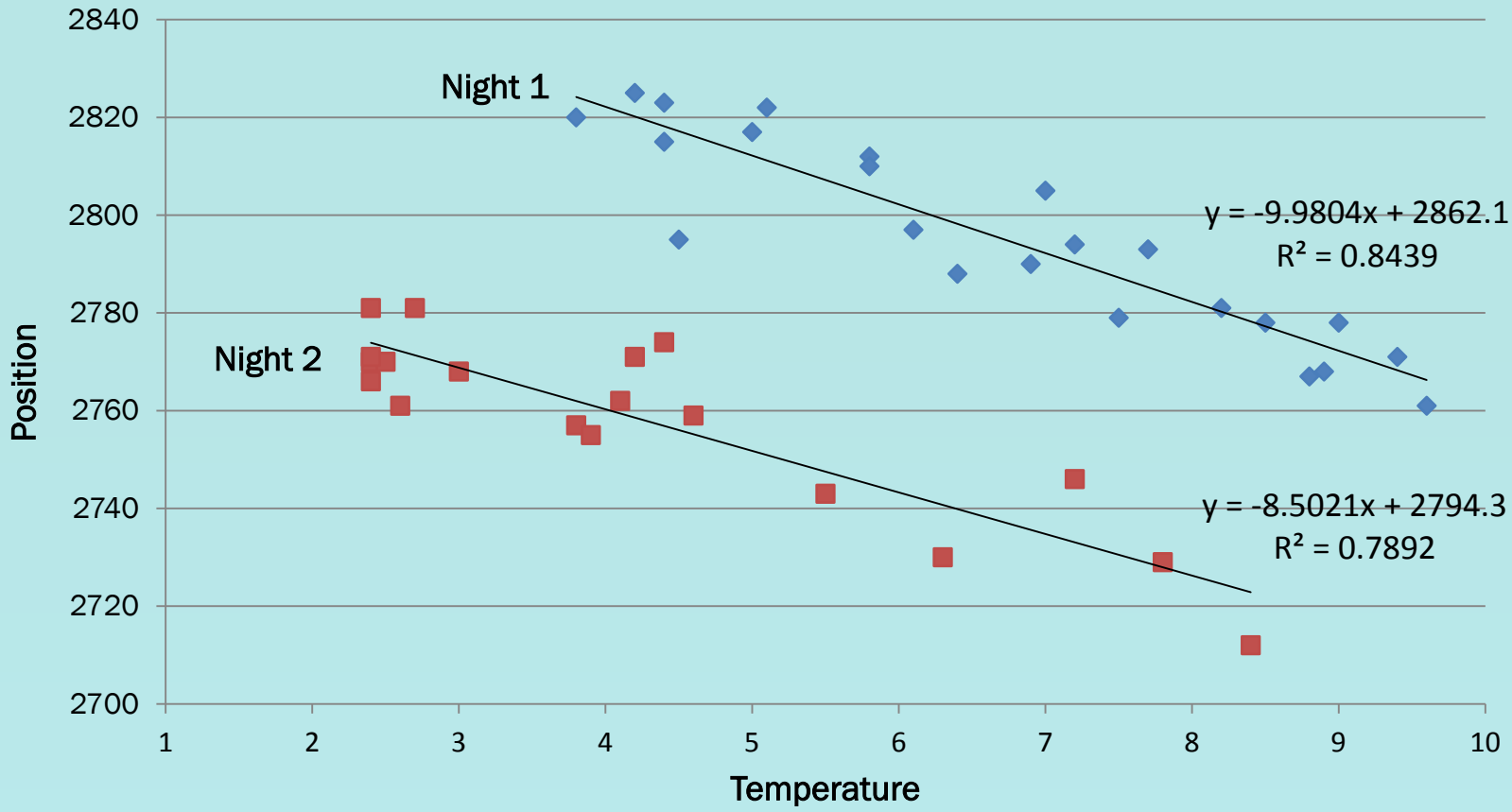
My 16” f/4.5 Newtonian

- Focus Convergence set to 1 Step, 10 Samples to assure adequate sampling
- Enabled AcquireStar with:
  - Zenith enabled
  - Return slew disabled
  - Meridian Cross disabled
  - PinPoint to center target star
- Binning = 1x1 (1.02 arc-sec/pixel)
- Seeing ~3 arc-sec FWHM

FocusMax

Temperature vs. Position

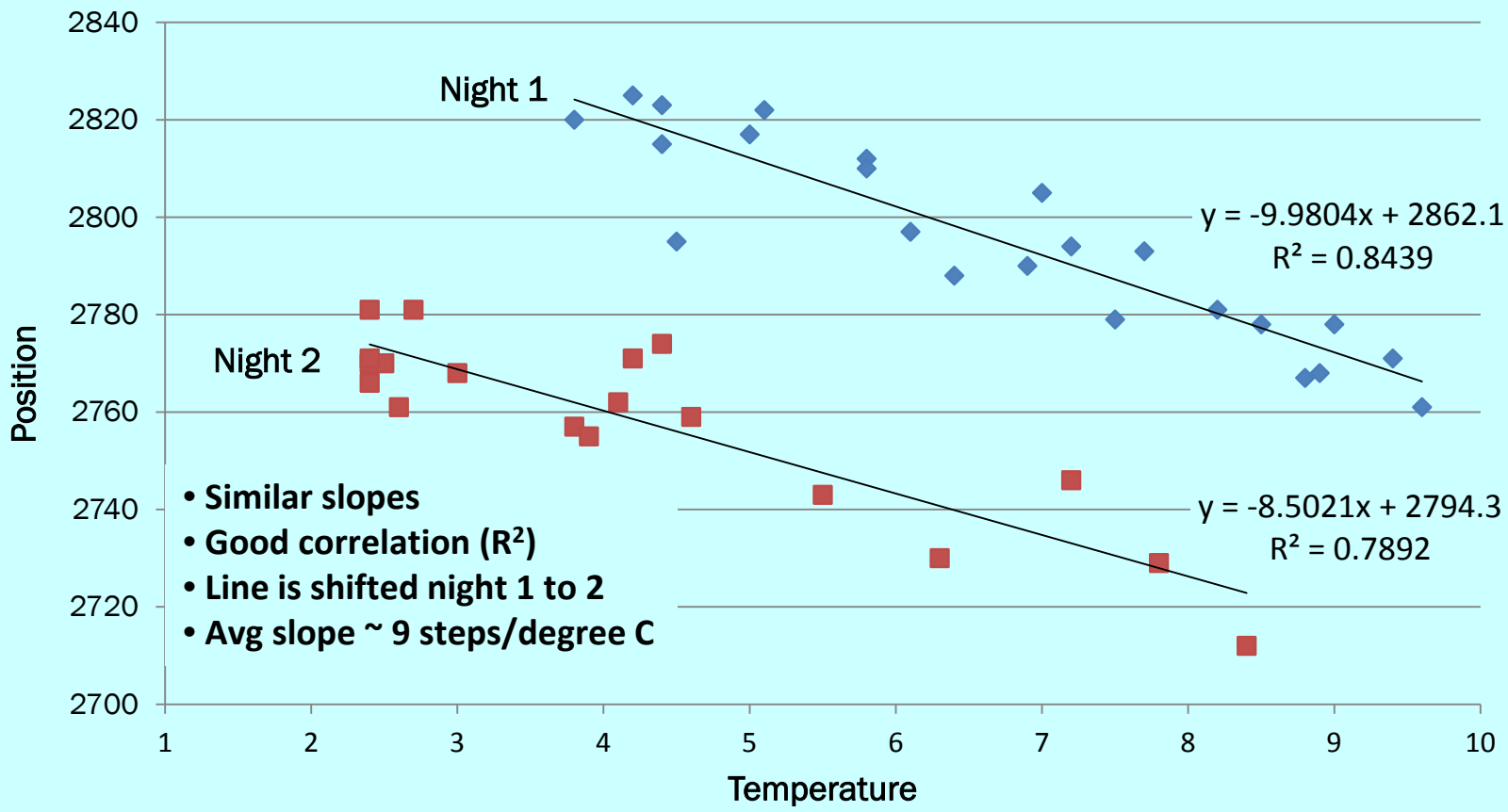
(Scatter Plot)



FocusMax

Temperature vs. Position

(Scatter Plot)



FocusMax

Temperature Compensation

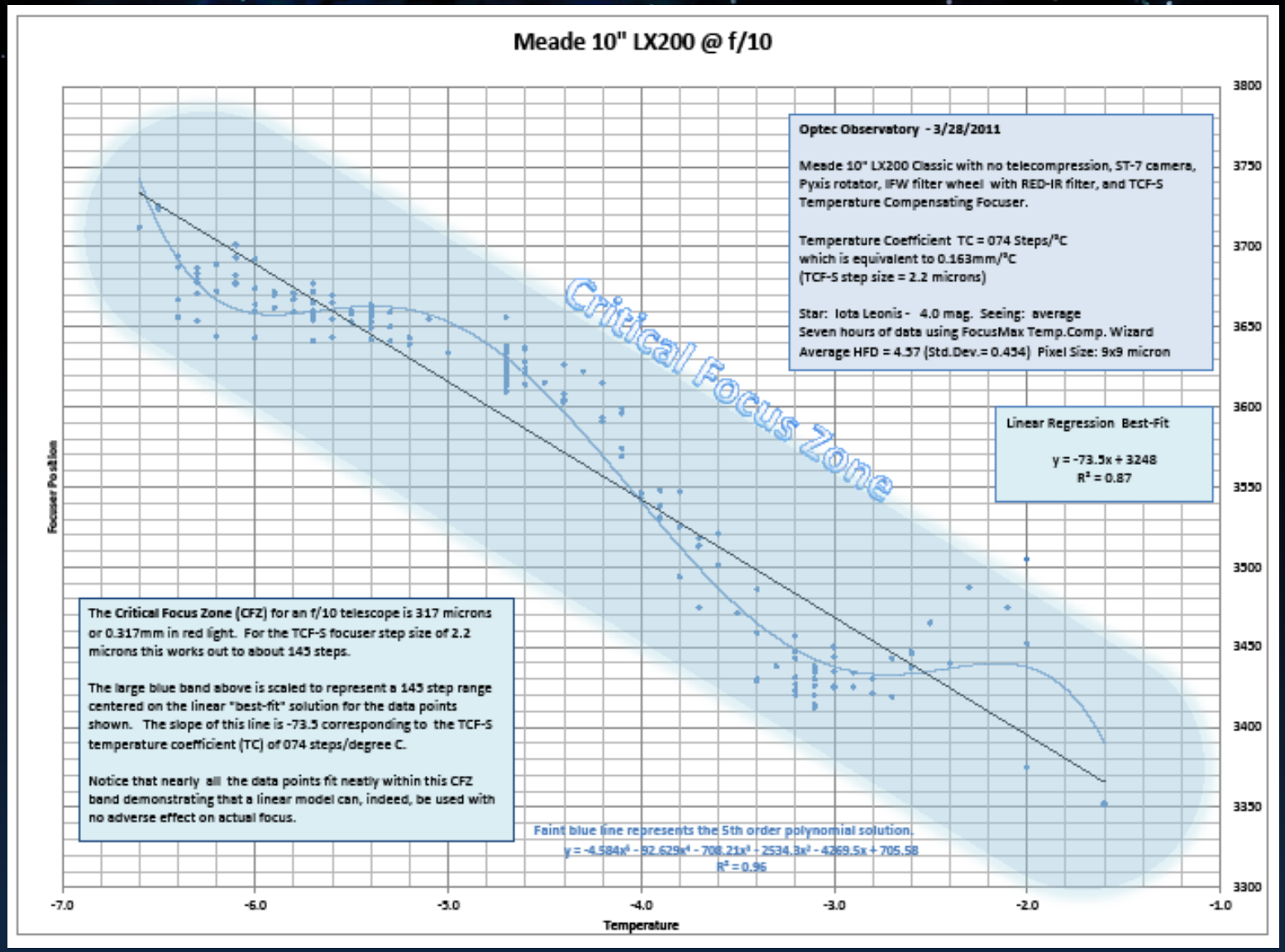
Averaged temperature coefficients (slopes) over several nights

Result

Able to extend time between autofocus from 60 minutes to 120 minutes

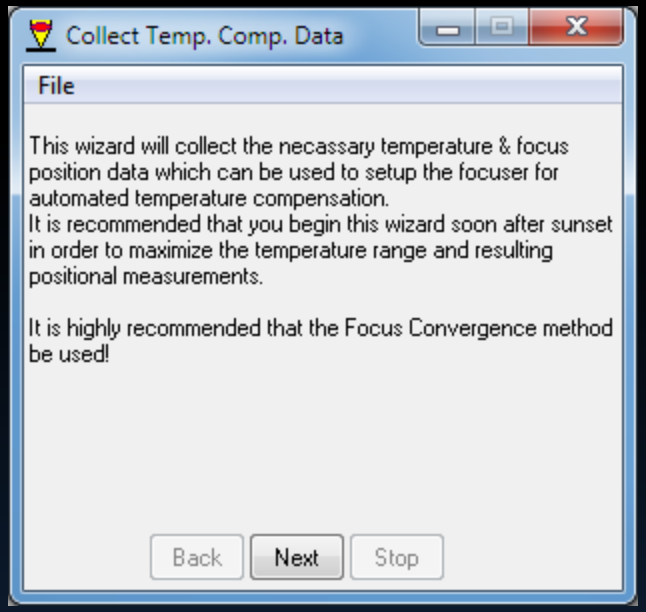
FocusMax

Jeff Dickerman - Optec



FocusMax

Temperature Compensation Wizard



- Collect temp & position data by performing repetitive focus runs
- Use AcquireStar to identify star at zenith throughout the night
- Use Focus Convergence to reduce focus errors
- Set time between autofocus runs
- Will park the telescope at end of session

Temperature Compensation

There is a lot more work to do!

- Not all focusers are created equal for temperature sensing
- How to handle non-linear responses
- Where to place probe for closed tube telescopes

Temperature Compensation

FocusMax V4:

- New autofocus routine that uses both sides of Vcurve
- Several different TC methods
- Will perform TC least square analysis on data
- Plot TC data
- Built in scripting capabilities
- Plot Profile data
- New focus plot graphics

FocusMax

Precision Focusing With FocusMax

CCD Astronomers using FocusMax
Love Focusing!

Steve Brady
http://focusmax.org
http://tech.groups.yahoo.com/group/FMaxUG