On Axis Guiding and Real Time Autofocus Solutions

Southwest Astrophotography Seminar 2014

Dr. Gaston Baudat

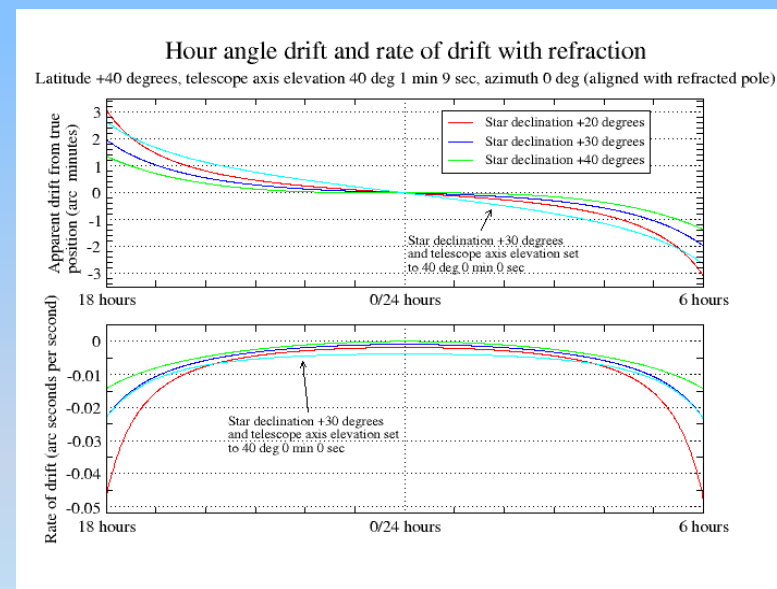
Innovations Foresight, LLC

Astro-photography challenges

A target must stay still for successful long exposures.
Accurate tracking and optimal focus are critical.
A ½ arc" error is visible under good seeing conditions.

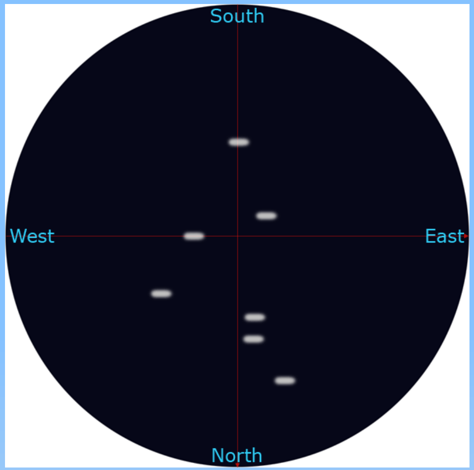
Common problems:

- Polar alignment, King's rate, …
- Mount mechanic and periodic errors, …
- Flexure(s), mirror/optics motions, …
- Focus shifts with temperature, …
- And more…



Auto-guiding & periodic refocusing are often required!

Common tracking errors



- <u>Periodic errors (PE):</u>
PEC helps but not necessary enough.
Active guiding is likely.

- <u>Polar alignment error:</u>
Drift & field rotation.
10 arc′ error , f=2 m, t=5′, fov=1°, @+35° elev.
Trail=8 microns , or 0.83 arc″.

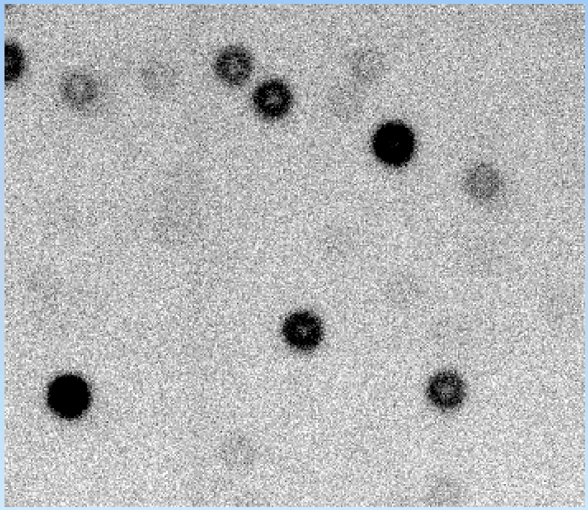
- <u>Flexure(s):</u>
OTA(s), mount, …, difficult to track and fix.
Active guiding may help (same optical axis)

Common focus errors

-Temperature changes:

OTA contraction , C11-Aluminium: ~350μm/ ºC (0.014"/ ºC).
CFZ = +/-134 μm @ F/10 -> focusing every ºC or less with good seeing (+/-44 *μm* @ 1/10 *λ error). Human hair Ø ~100μm.*
Mirror Radii: Optical powers, different thermal inertias.

- Mirror shift, flexure(s):



Mirror shifts with location or meridian flip.
Alignment of optics may be altered.

Out of focus could lead to other aberrations

Image quality: FWHM

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FWHM (Full Width at Half Maximum), correlated to PSF:

From space, diffraction limited (Airy disk) $FWHM = 2 \cdot 10^4 \lambda / D \; arc''$

D = 0.3m, λ=550nm, -> 0.39 arc" (Rayleigh's limit)

From Earth, seeing limited (Gaussian like) $FWHM = 0.5 \; to \; 3 \, arc''$

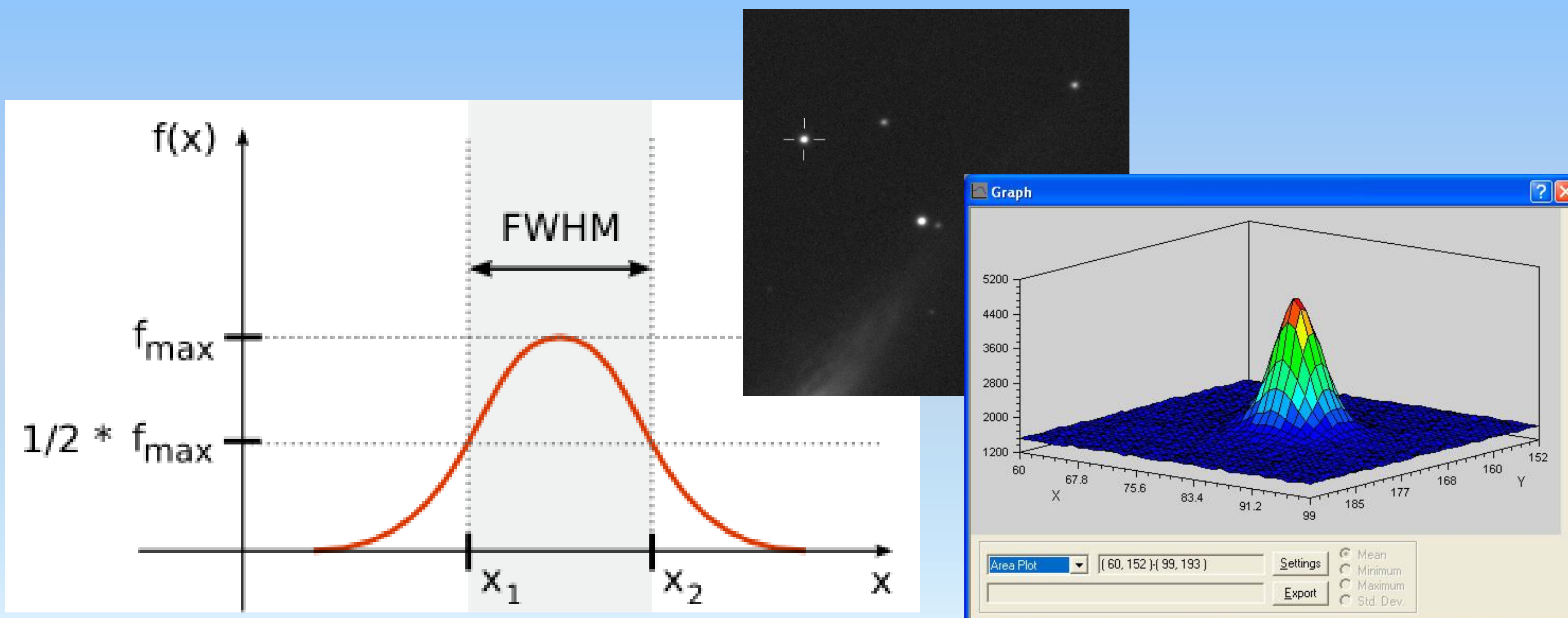
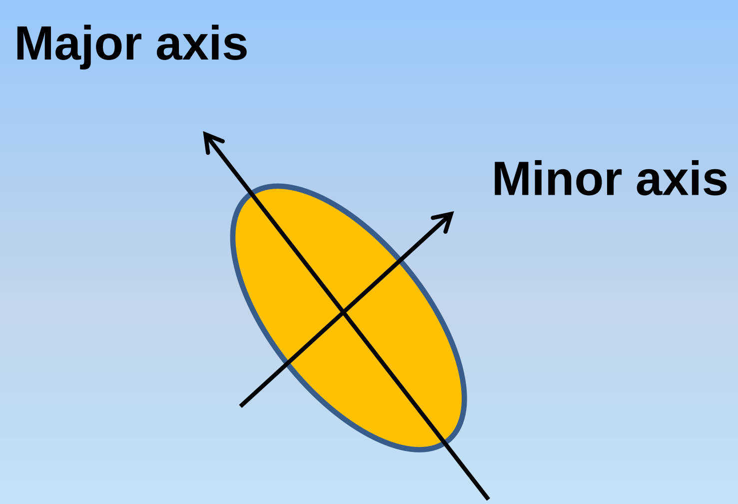


Image quality: Absolute Roundness

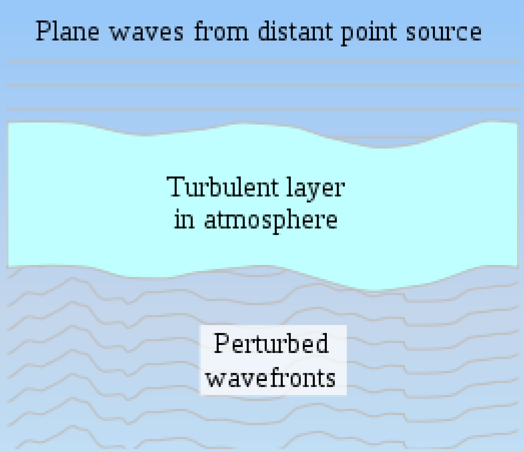
ARDN = (Major FWHM - Minor FHWM) / (Major FWHM + Minor FWHM)

An ARDN < 0.1 (10%) is not perceived by human inspection



How much tracking error is too much?

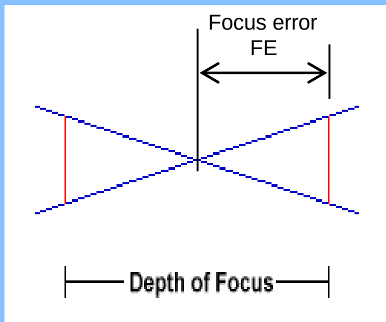
Rule of thumb: **RMS tracking error < 1/4 FWHM$_{seeing}$**

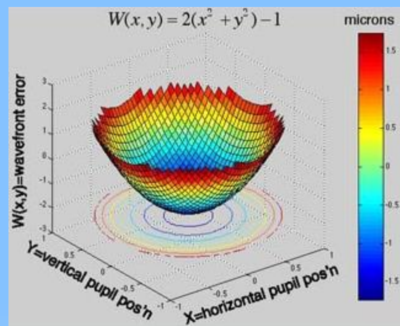


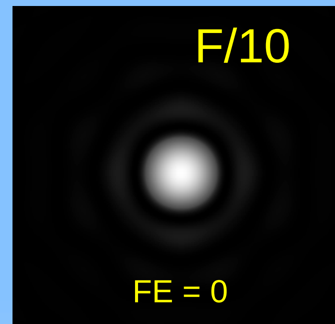
RMS tracking error v.s. seeing for a absolute roundness < 10% (Exposure > 1 second)

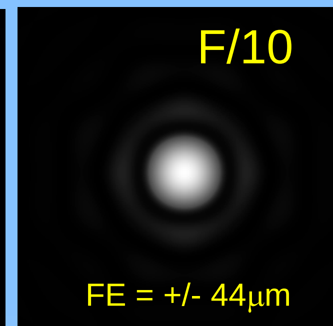
Seeing	Excellent 0.5 arc”	Good 1.0 arc”	Average 2.0 arc”	Poor 3.0 arc”
RMS error	0.13 arc”	0.25 arc”	0.50 arc”	0.75 arc”

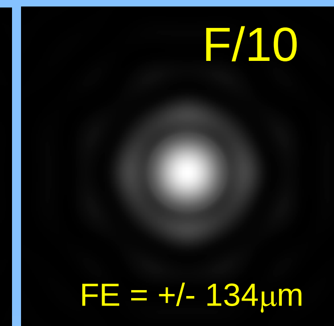
How much focus error is too much?





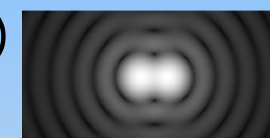






Wave front error: $0\ \lambda$ $\lambda/10$ $\lambda/3$

FE $\lambda/3$: +/- 2.44 x F^2 x λ =CFZ (Rayleigh's limit, angular resolution)



FE for $\lambda/10$: +/- 0.8 x F^2 x λ =~1/3 CFZ

Rule of thumb: **Focus error < $\lambda/10$**

F/# λ = 550 nm	F/3	F/6	F/8	F/10
Focus error $\lambda/10$	**+/- 4 μm**	**+/- 16 μm**	**+/- 28 μm**	**+/- 44 μm**
CFZ error $\lambda/3$	**+/- 12 μm**	**+/- 48 μm**	**+/- 86 μm**	**+/- 134 μm**

On-Axis Guiding (ONAG®)

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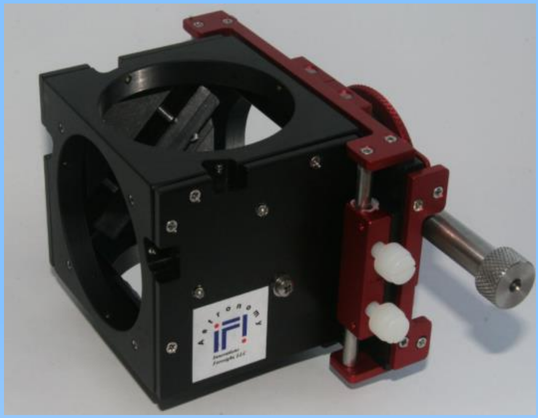
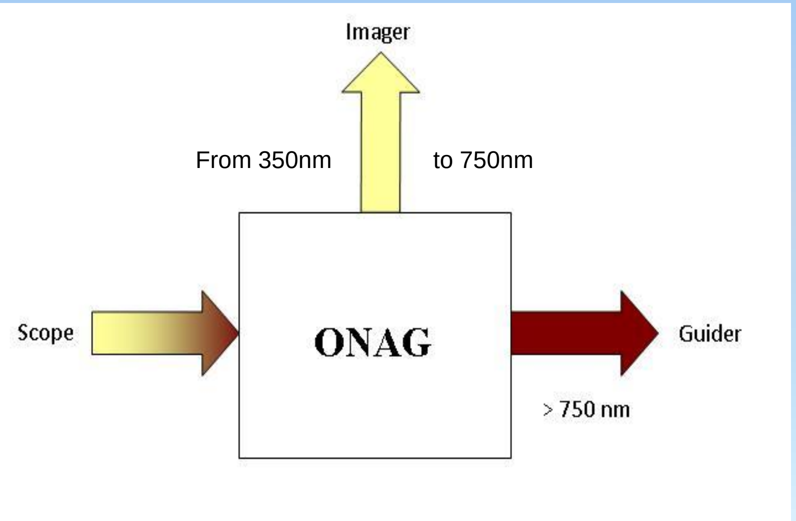
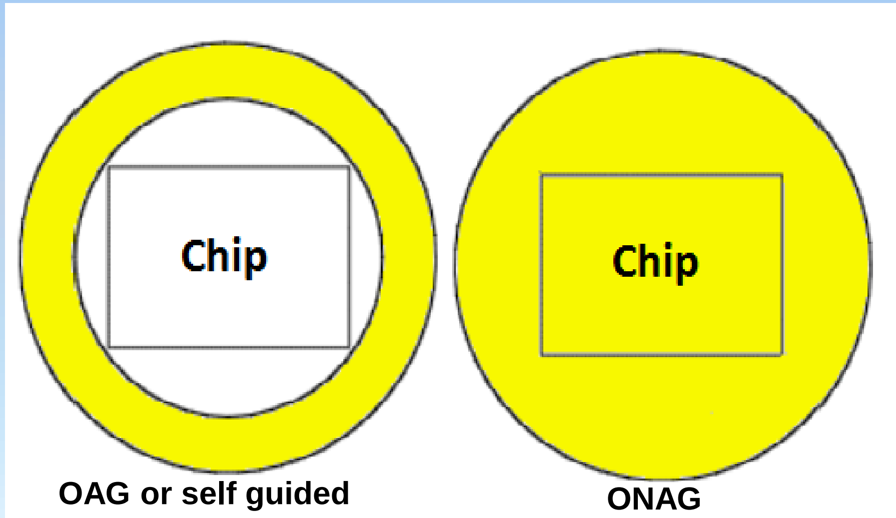
SharpLock

<u>Concept:</u> Split incoming light (Visible v.s. NIR)



- Same scope, same aperture, no-flexure.
- Large field of view (on and off-axis).
- No rotation (same flat frames, stay in focus).
- Seeing effects significantly reduced in NIR.
- Allow for true real time auto-focus (*SharpLock*).





ONAG® XT overview

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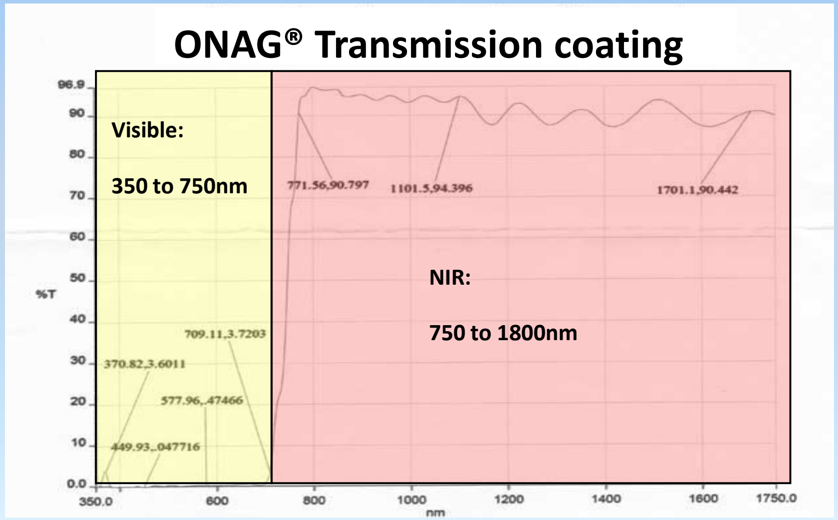
SharpLock

Multi-coated dichroic mirror : Laser aligned at factory
Weight : <800g (1.8 lbs)
Reflection (visible 350nm-750nm): >98% typical
Transmission (NIR 750nm-1800nm): >90% typical
X/Y stage exploration circle (guider): Ø 44mm (1.7”)

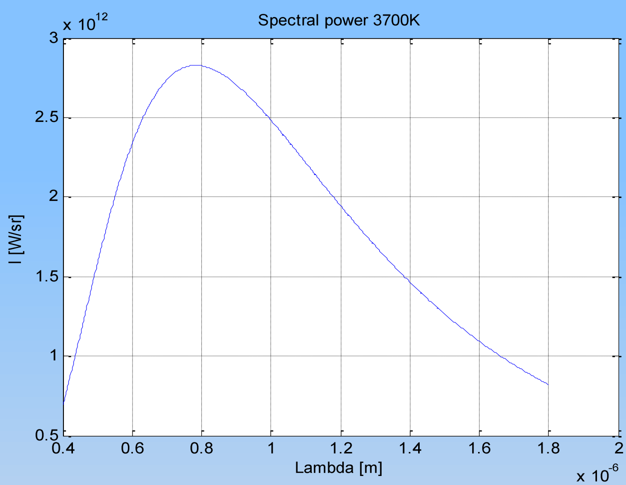
Astronomy magazine 2012 Star Products

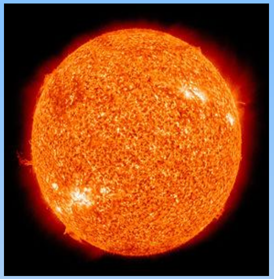
HOT PRODUCT 2012 SKY & TELESCOPE



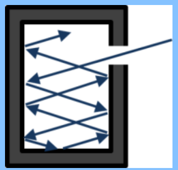
Guiding in Near Infrared (NIR)

The black body law describes star spectrums





$$I(\lambda,T)=\frac{2hC^2}{\lambda^5\left(e^{\frac{hC}{kT\lambda}}-1\right)}$$



Star spectral classification

Class	Surface T °K	% of stars
O	>33,000	0.00004
B	10,000-33,000	0.13
A	7,500-10,000	0.6
F	6,000-7,500	3
G	5,200-6,000	7.6
K	3,700-5,200	12.1
M	<3,700	76.45

> 75% main sequence stars surface temperatures < 3700°K (class M)

Black Body & Quantum Efficiency

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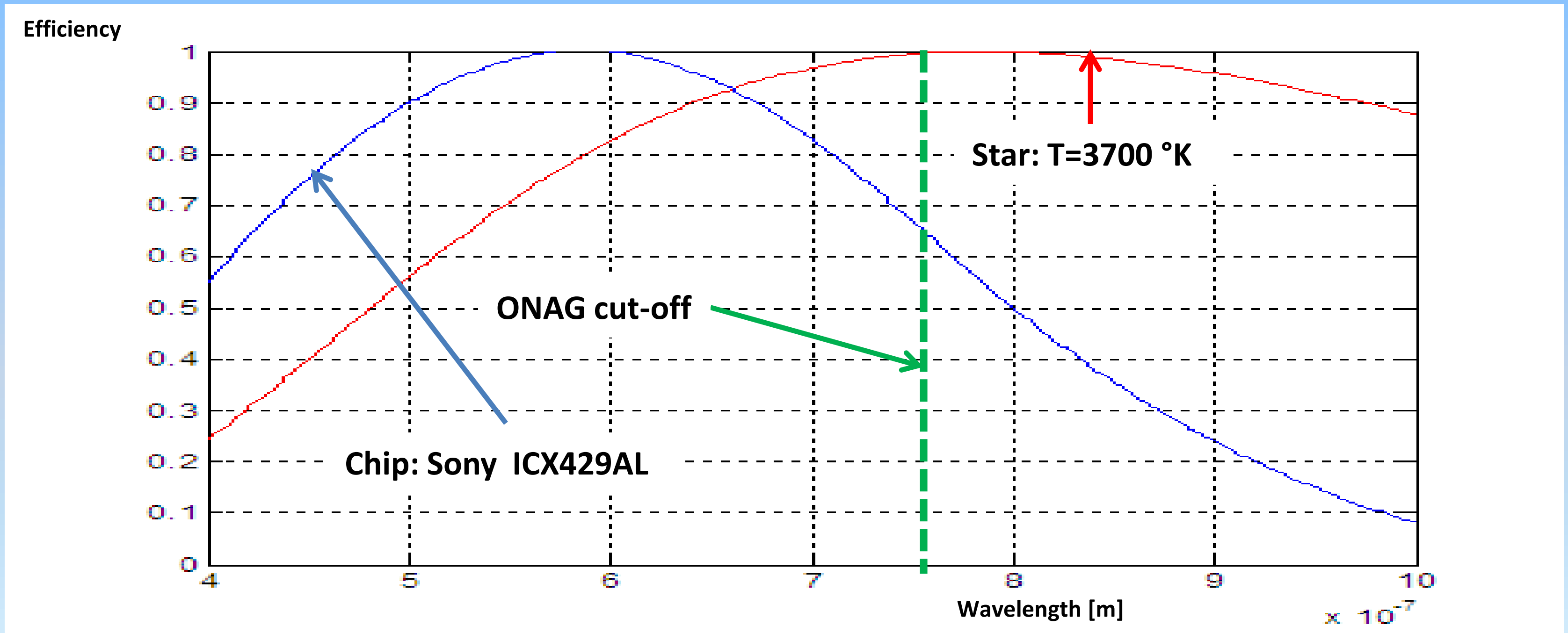
SharpLock

NIR guiding consideration:

Star spectrum x Optical transfer function x Sensor efficiency

Atmospheric extinction neglected

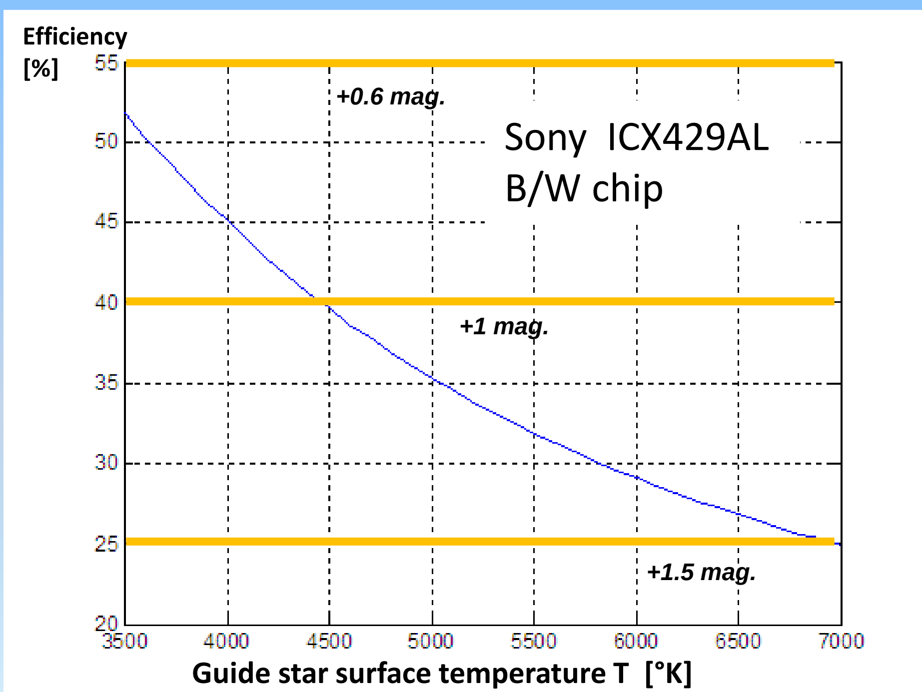


ONAG® efficiency

Full spectrum (350 – 1000nm) v.s. ONAG NIR range (>750nm):

$$\text{Efficiency} = \left. \frac{\text{Enery}_{Full} - \text{Energy}_{ONAG}}{\text{Power}_{Full}} \right|_{T[^\circ K]}$$

>75% main sequence stars T< 3700 °K
>99% main sequence stars T< 6000 °K



Guide scope versus ONAG:

80mm (3.2") guide scope versus C11
$3.15^2/(11^2 x0.89)=0.09x$, loss=+2.6 mag
ONAG: gain 1.5-2.6=-1.1 or 2.8x (worst case)

ONAG typical guide star magnitude:

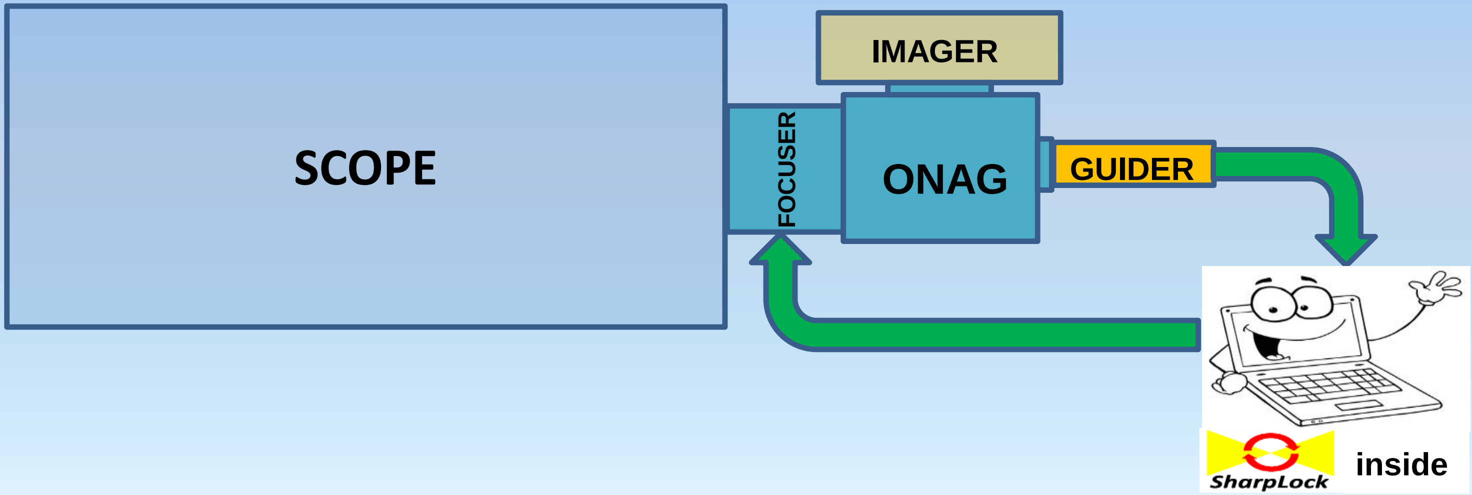
Scope: C11 @ F/10
Guiding: ONAG® & SX-Lodestar - 1 second
Guide star typical magnitude: 9^{th}

SharpLock Overview

SharpLock leverages the ONAG technology for providing the only real time auto-focus in the market:

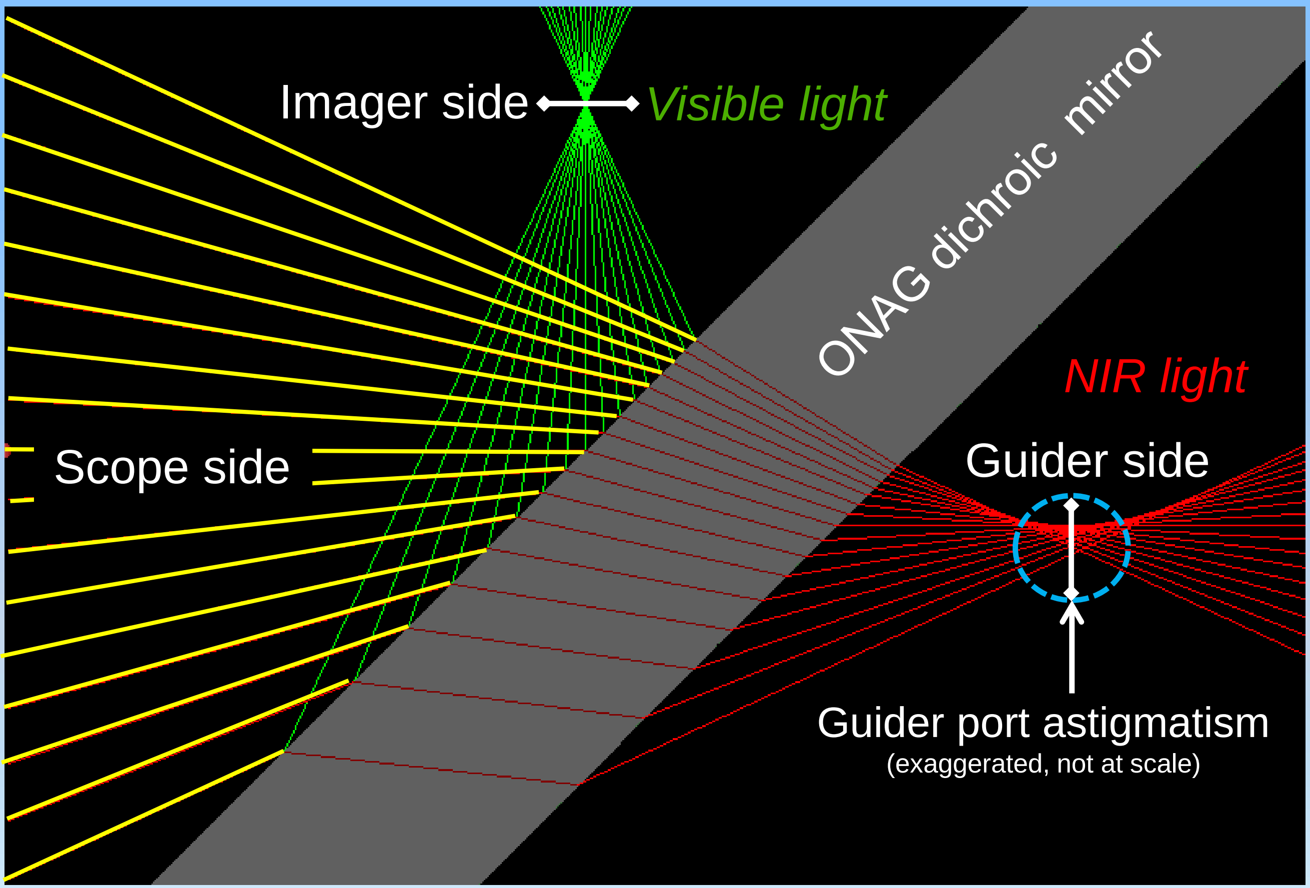
- Continually maintains critical focus without any interruptions in imaging operations. Scope remains on target.

- Uses the guide star images for focus directionality & quality assessments while auto-guiding.



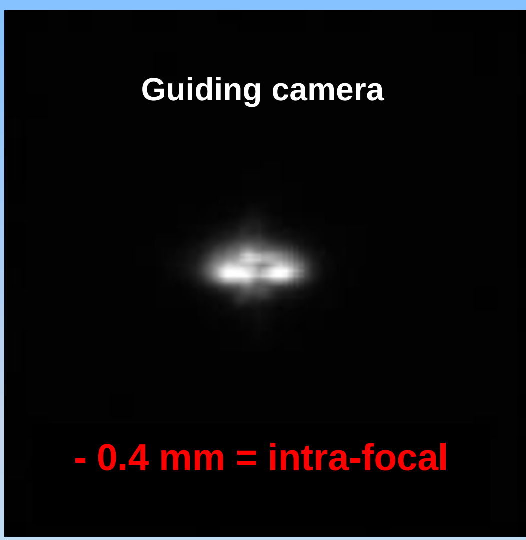
Guide star profile

Guide star a best focus:



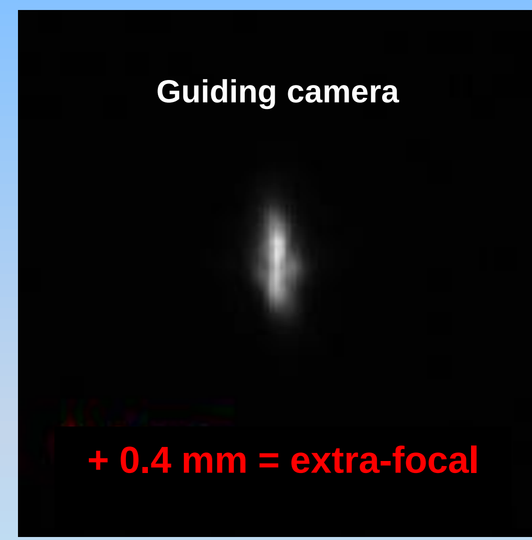
Out of focus guide star

The star shape is function of focus position (in, out focus).
SharpLock retrieves focus directionally from shape analysis.



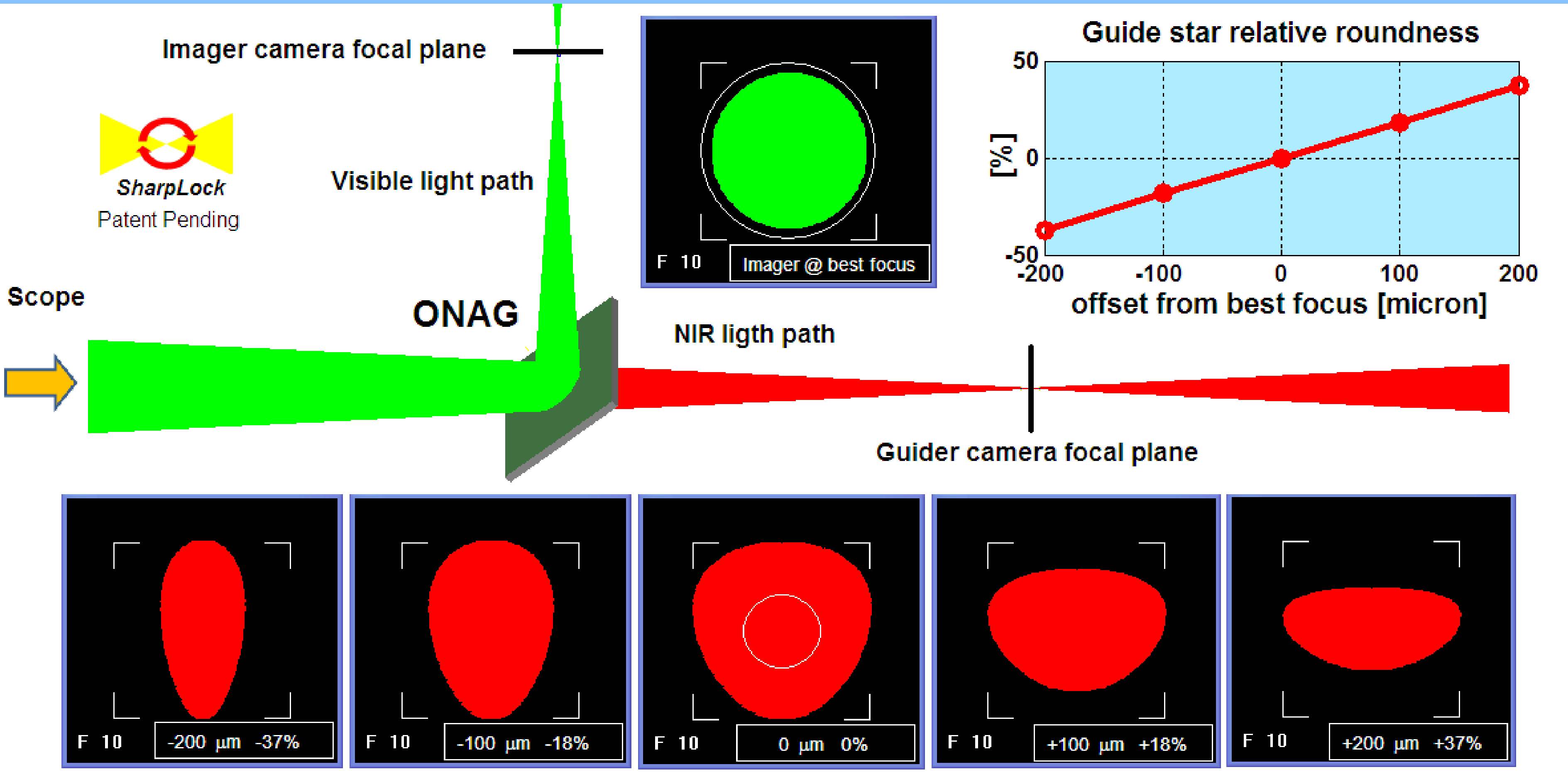
- 400 μm from best focus

at best focus



+ 400 μm from best focus

SharpLock Optical concept

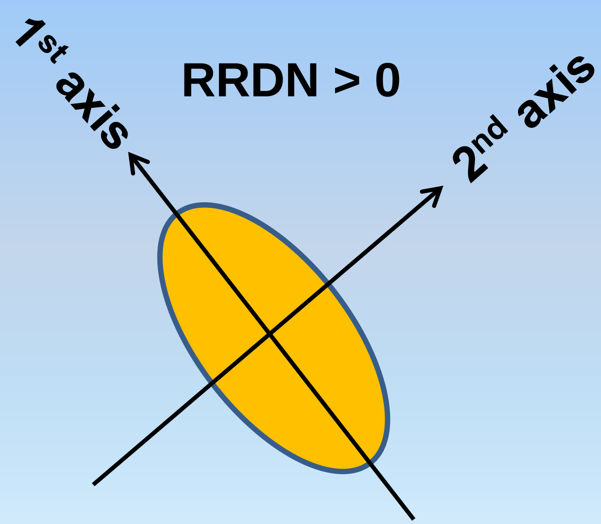


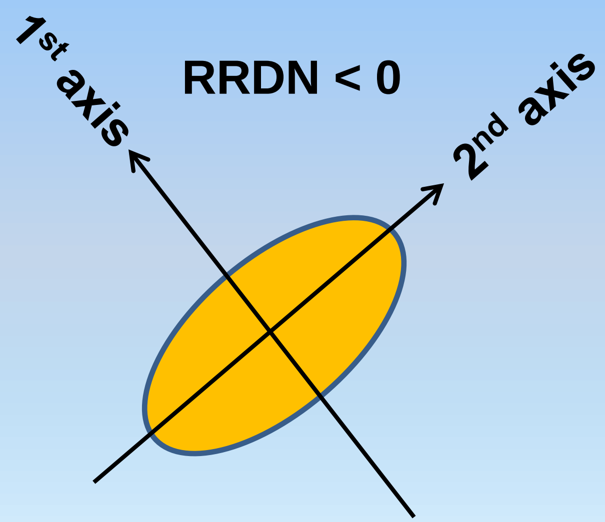
Guide star shapes versus best focus offsets

Relative Roundness

RRDN = (1st FWHM – 2nd FWHM) / (1st FWHM + 2nd FWHM) x 100 [%]

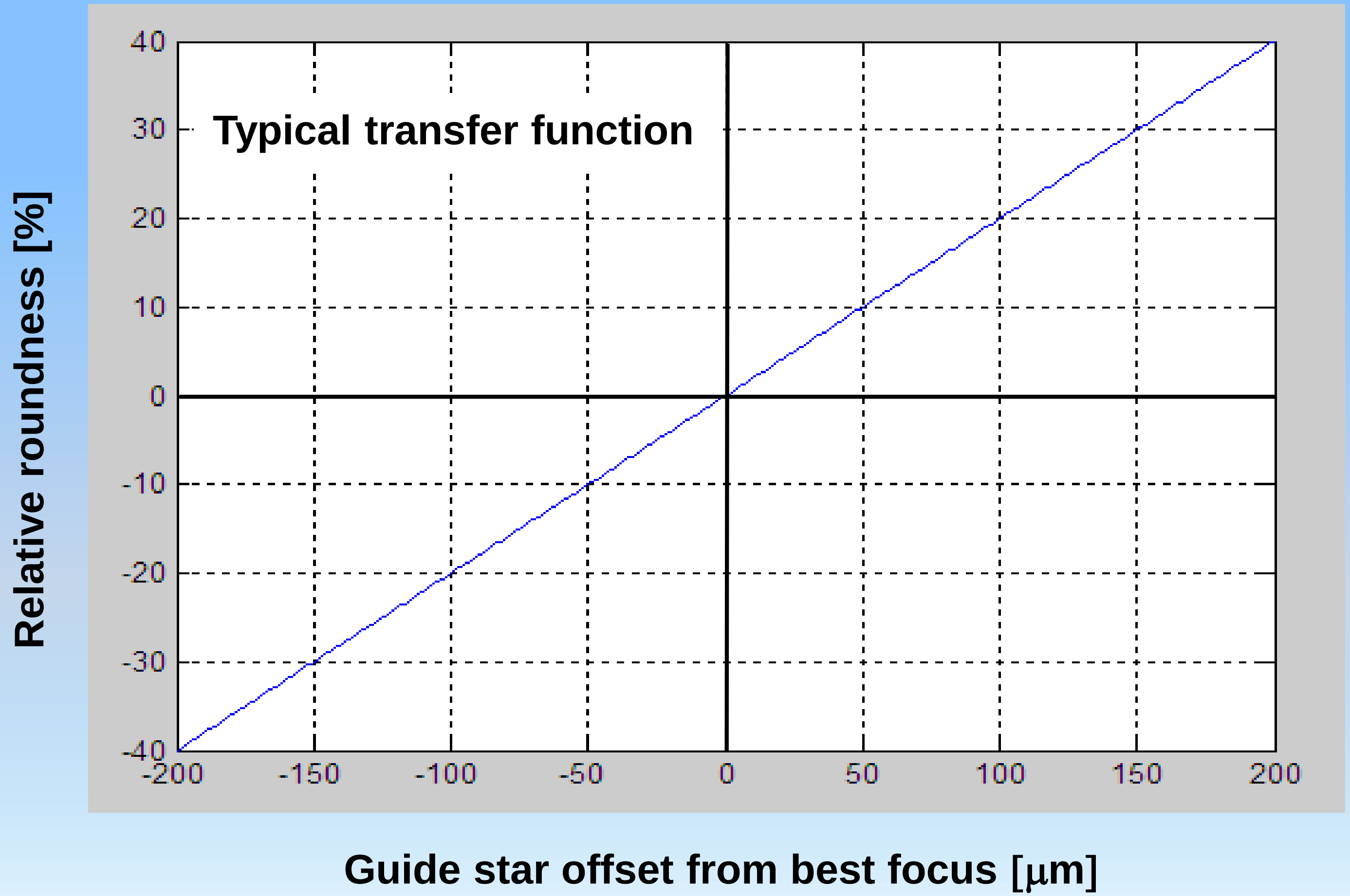
- RRDN carries directionality information (signed).
- 1st & 2nd axes are defined during the SharpLock calibration.
- They are reference axes related to the guider camera frame.





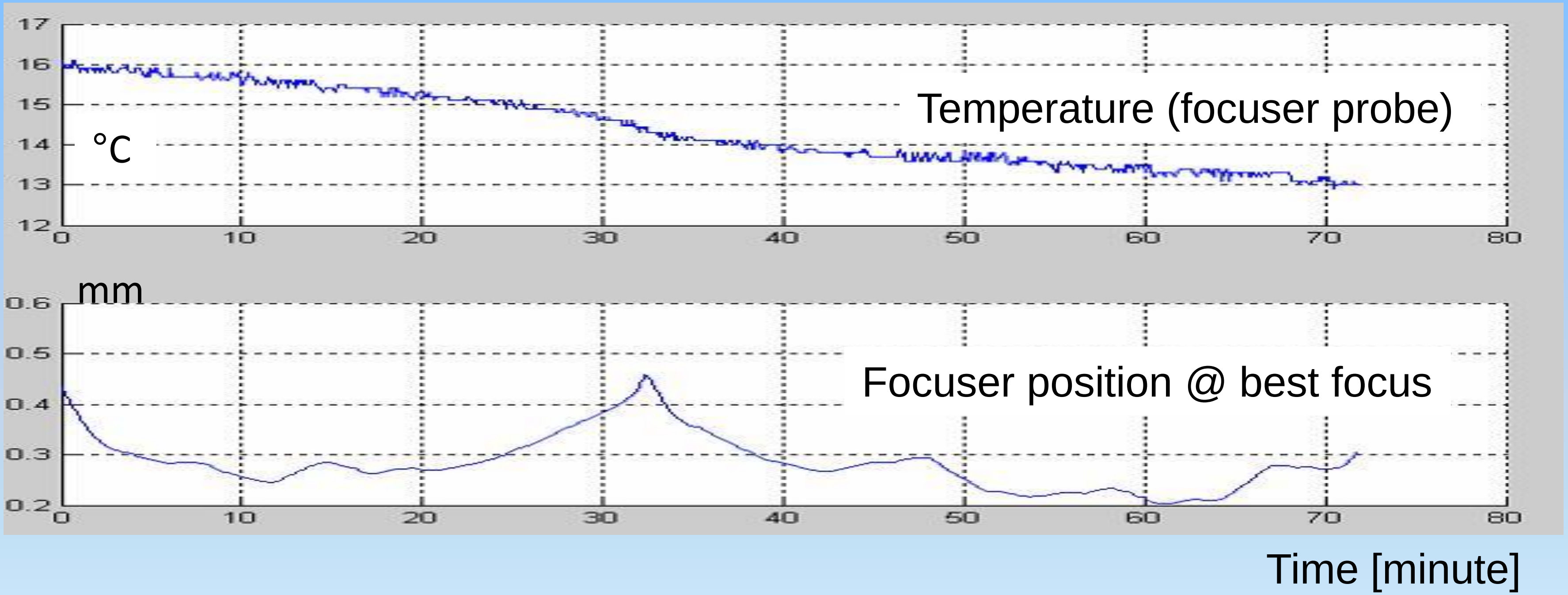
SharpLock Transfer function

Relationship between focuser position and guide star roundness



Focus shift analysis with *SharpLock*

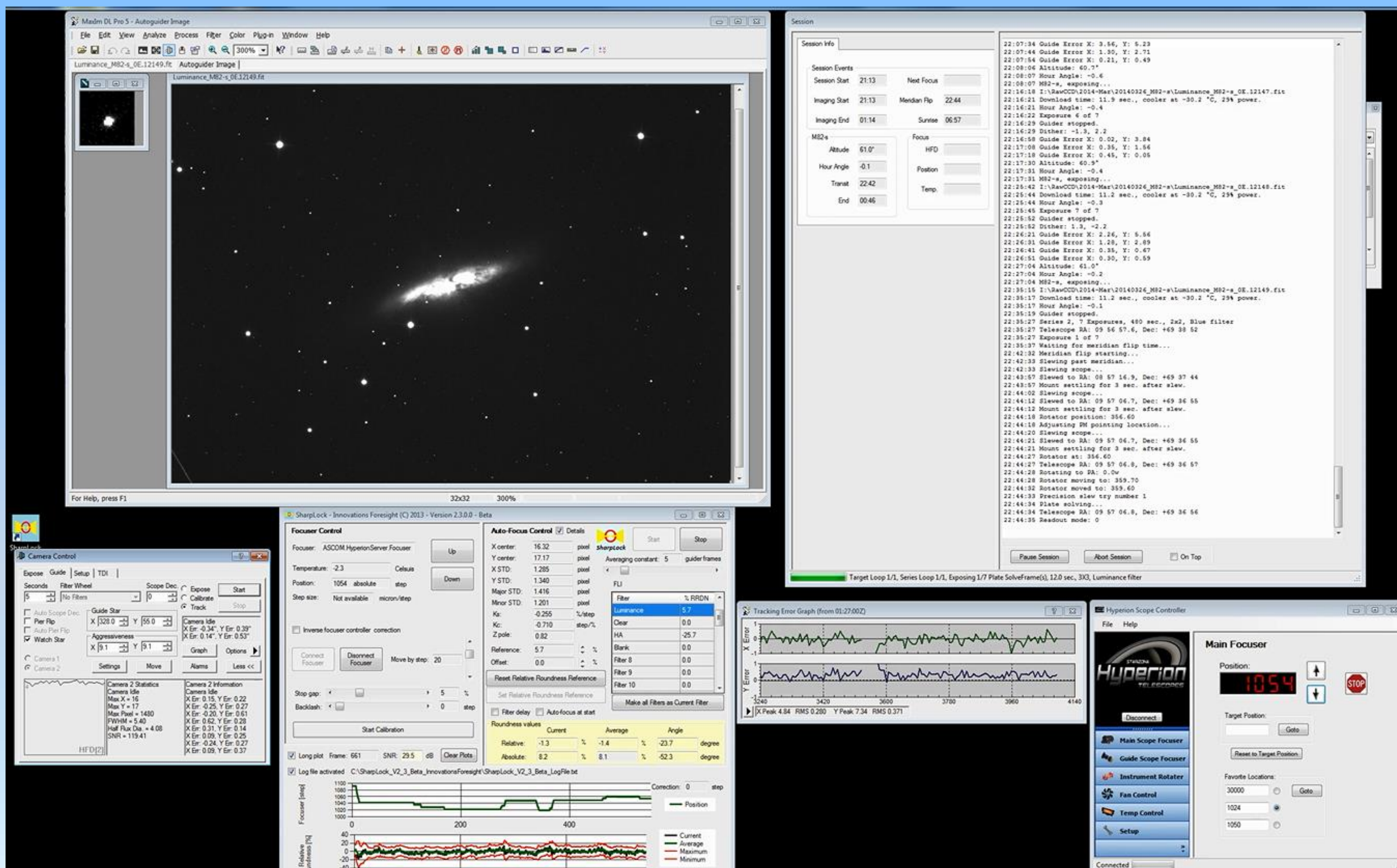
- 10" RCT F/8, carbon fiber OTA + fans, absolute focuser.
- One hour temperature stabilization period.
- Target near the zenith (no mount pier flip, same side).



Focus changed up to 20 μm/minute (F/8 CFZ=+/-86μm)!

Periodic refocusing versus *SharpLock* side by side

CCDAP, same scopes, mounts, time & location. Credit Frank Colosimo



Periodic refocusing v.s. *SharpLock*
M82 - 27 March 2014

Location: Blue Mountain Vista Observatory, New Ringgold PA (USA)
Scopes/Mounts: Hyperion 12.5" F/8 (same model) / PME
Imager #1: SBIG STL-11000, 9x9μm, periodic focus (every filter or 30')
24 frames (LRGB): 4h46' ~ 12' per frame (include periodic focus)
Imager #2: Apogee U8300, 11x11μm, ONAG +*SharpLock*
28 frames (LRGB): 4h22" ~ 9' per frame (no interruption)

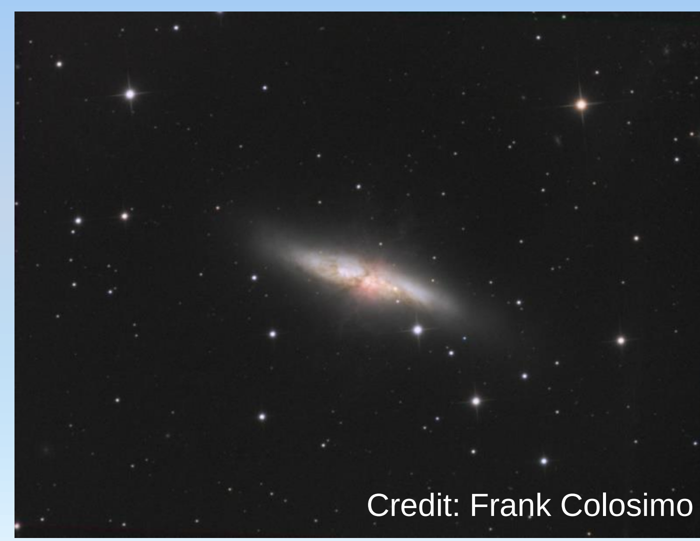
Saving: 2.6' per frame, total for 28 frames = 1h13' or 27%


Credit: Frank Colosimo

Periodic focus

Stacked FWHM in arc"

L: 2.3
R: 2.5
G: 2.5
B: 2.6


Credit: Frank Colosimo

ONAG + *SharpLock*

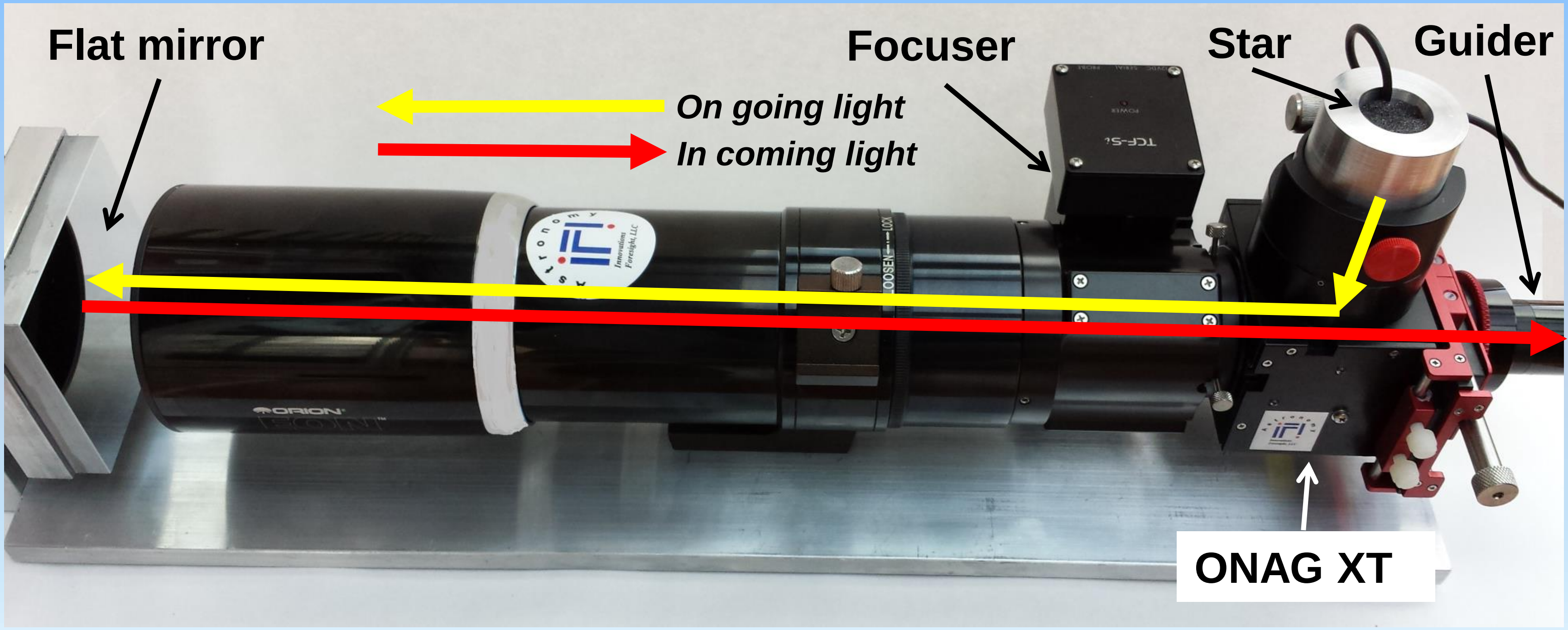
Stacked FWHM in arc"

L: 2.4
R: 2.2
G: 2.2
B: 2.4

SharpLock demonstration bench

80mm F/6.25 refractor + OPTEC absolute focuser + ONAG XT:

- Imager port with an artificial star, guider port with a guiding camera.
- Flat mirror reflecting back the artificial star image toward the guider.



Thank you!

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Clear skies!