

Full Frame Guiding & Focusing

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A target must stay still for successful long exposures. Accurate tracking and optimal focus are critical. A ¹/₂ arc" tracking error maybe visible under good seeing conditions.

Common problems:

- Polar miss-alignment
- Mount mechanic and periodic error(s)
- Flexure(s)
- Focus shifts with temperature, location, ...

Require auto-guiding and periodic refocusing

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OTA contraction , C11-Aluminium: ~130 μ m/ °C (0.005"/ °C). CFZ = +/-134 μ m @ F/10 -> focusing every °C or less. Human hair Ø~100 μ m. Mirror Radii: Optical powers, different thermal inertias.

- <u>Mirror shift, flexure(s)</u>:

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

Out of focus could lead to other aberrations



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Image quality: Absolute Roundness

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

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



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How much tracking error is too much? Innovations Foresight Rule of thumb: RMS tracking error < 1/4 FWHM _{seeing}					
Plane waves from distant point source	RMS tracking error v.s. seeing for a absolute roundness < 10% (Exposure > 1 second)				
Turbulent layer in atmosphere	Seeing FWHM	Excellent 0.5 arc"	Good 1.0 arc"	Average 2.0 arc"	Poor 3.0 arc"
Perturbed wavefronts	RMS error	0.13 arc"	0.25 arc"	0.50 arc"	0.75 arc"
Example: Seeing 2 arc", scope focal = 2m, Pixel = 8 microns FWHM seeing = 6.64 μm or 0.83 pixel RMS tracking error < 1.68 μm or 0.21 pixel					
1 μm ⇔ 4/100,000″					
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Full frame image registration

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Goal:

Retrieve dX, dY image registration values from the all frame.



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Digital Image Correlation

Digital image correlation extracts image registration. Below image correlation intensity 2D and 3D color plots:



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SNR=20 dB (10x), one star, no seeing, dX=dY=30 pixels.



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Astronomical Image Correlation Innovations Foresight Normalized correlation image (colored 2D and 3D plots). SNR=20 dB, one star, no seeing. Correlation peak clearly visible but noisy.



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400 450

150 200 250 300 350 400 450



Normalized correlation image (colored 2D and 3D plots). SNR=0 dB, one star, no seeing. Correlation peak no visible, signal is beneath the noise floor.



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< < n % <

Image Correlation, with advanced statistical processing

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Normalized correlation image (colored 2D and 3D plots). SNR=0 dB, one star, no seeing (same raw images). Correlation peak clearly visible, sub-pixel localization.





Good SNR, 10 stars, various magnitude, no seeing

Raw images (guider).

SNR 1.6 to 20 dB, 10 stars, no seeing, dX=dY=30 pixels.



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Image Correlation, full field, with advanced statistical processing

Normalized correlation image (colored 2D and 3D plots). SNR 1.6 to 20 dB, 10 stars (diff. mag. -2.3 to 0). Correlation peak clearly visible, sub-pixel localization.





Poor/bad SNR, 10 stars, various magnitudes, no seeing

Raw image and correlation images, advanced processing. SNR -32 to 0 dB, 10 stars, diff. mag. -4 to 0, no seeing. Correlation peak clearly visible, sub-pixel localization.



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Seeing

- Astronomical seeing is the blurring of astronomical objects caused by Earth's atmosphere turbulence and related optical refractive index variations (air density fluctuations).
- It impacts the intensity (scintillation) and the shape (phase) of the incoming wave front.
- This presentation will ignore scintillation.



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Isoplanatic patch

The angle for which the wavefront error remains almost the same ($\sim\lambda/6$) is known as the isoplanatic angle:

$$\theta_0 \cong 0.31 \frac{r_0}{h}$$

 $h \sim 5$ km, θ_0 is usually few arc-second across (@550nm): $r_0 = 50$ mm $\rightarrow \sim 0.6''$ $r_0 = 200$ mm $\rightarrow \sim 2.6''$



 $heta_0$ increases as $\lambda^{6/5}$





AO operation is usually only effective in a very narrow FOV.





Fair SNR, one star under seeing limited condition

Raw image & registration scatter plot (100 samples). SNR=6 dB (2x), one star, seeing (wander) 2 pixel rms. **Green dot:** correlation, **blue cross:** traditional centroid.





Poor SNR, one star under seeing limited condition

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Raw image & registration scatter plot (100 samples). SNR=0 dB (1x), one star, seeing (wander) 2 pixel rms. **Green dot:** image correlation.





Fair SNR, 4 stars, same mag. under seeing limited condition

Raw image & registration scatter plot (100 samples). SNR=6 dB (2x), 4 stars (same mag.), seeing 2 pixel rms. **Green dot:** image correlation, **blue cross:** constellation centroid, **red diamond:** one star centroid (brightest, in red).







Full frame auto-guiding no registration error

Comet against a star field. dX=dY=0 pixel. (Crosshairs centered to an arbitrary star for visualization only)







Full frame auto-guiding after guiding corrections

Comet against a star field. dX=dY=0 pixel. (Crosshairs centered to an arbitrary star for visualization only)



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Out of focus guide star with an ONAG

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The star shape is function of focus position (in, out focus). This allow retrieving focus directionally from shape analysis. The same concept is applied to the all guider frame.



10/29/2014

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