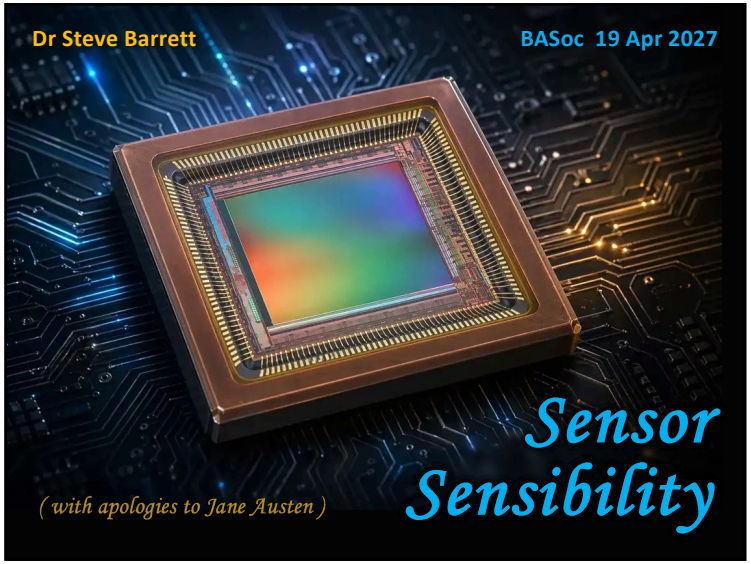


Contents

Optics
Focal length and *f*-number

Sensors
Chip size and Pixel size



Field of View
How much sky can be imaged?

Resolution
How much detail can be captured?



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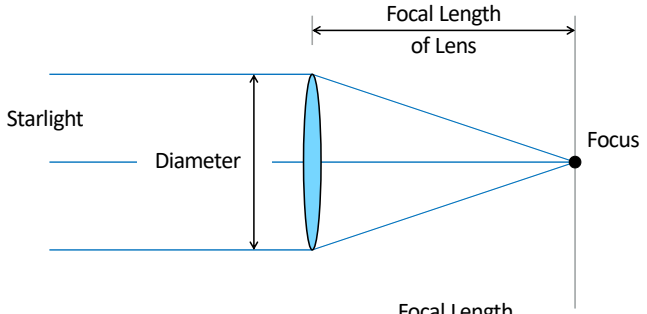
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Optics

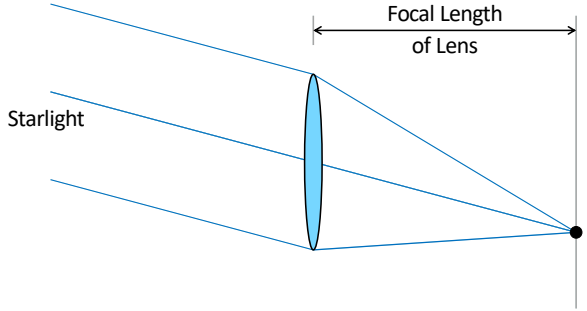


f-number = Focal Ratio = $\frac{\text{Focal Length}}{\text{Diameter}}$

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Optics

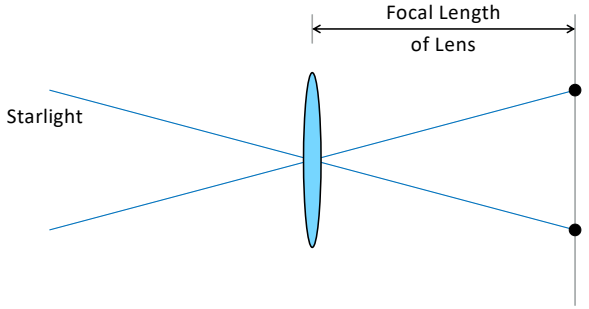


Note that the Focal Length does not depend on the angle of incoming light

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Optics



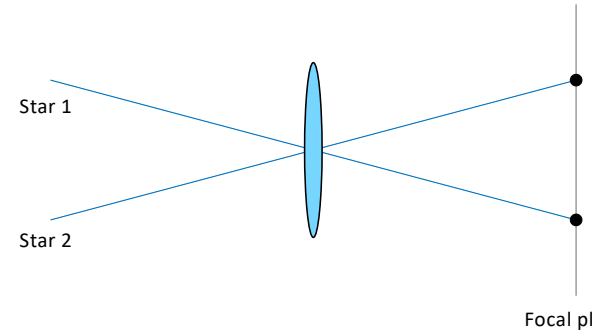
For clarity, only the central light ray will be shown in these ray diagrams

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Optics

Every object (left) has a corresponding image in the focal plane (right)



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Field of View

Optics

Focal length and *f*-number

Sensors

Chip size and Pixel size



Field of View

How much sky can be imaged?

Resolution

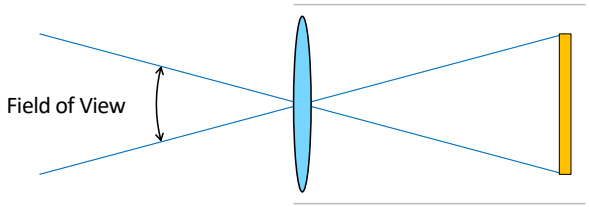
How much detail can be captured?



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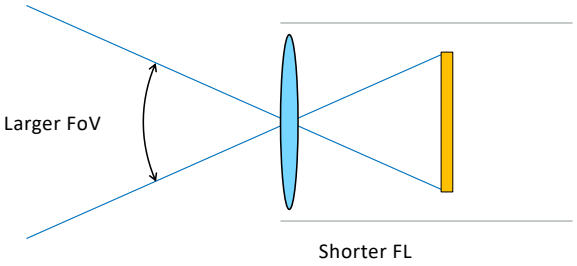
Field of View

An imaging sensor placed at the focal plane defines the image field of view



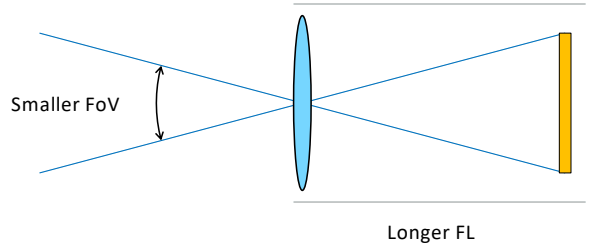
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Field of View



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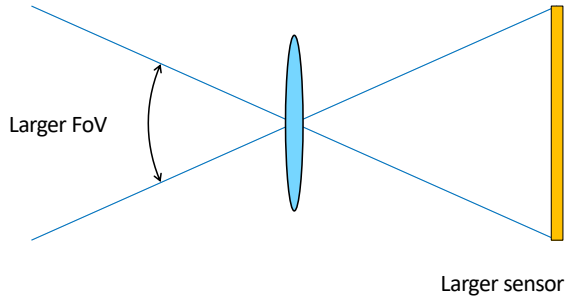
Field of View



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Sensor Sensibility

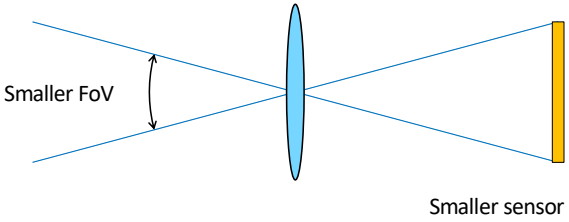
Field of View



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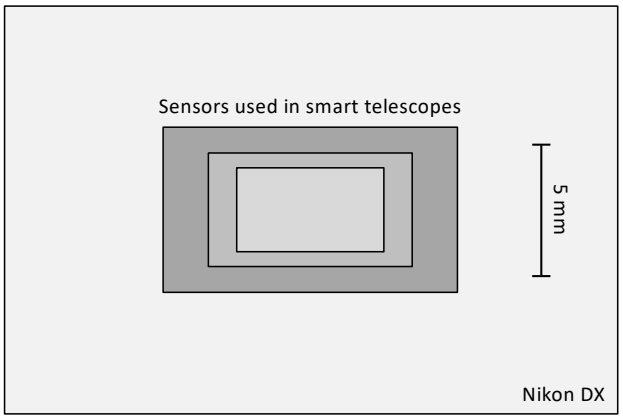
Field of View



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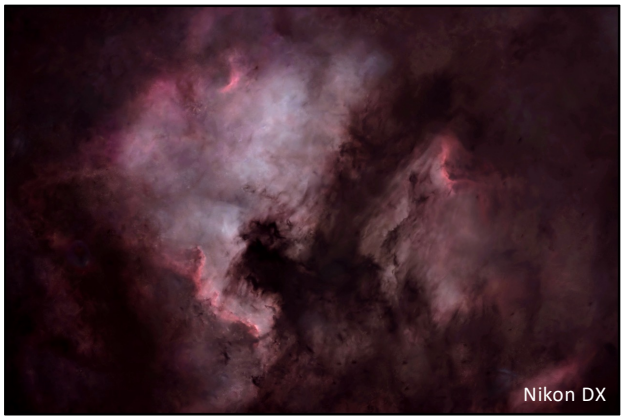
Sensor Sizes



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Sensor Sizes



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Resolution

Optics

Focal length and *f*-number

Sensors

Chip size and Pixel size



Field of View
How much sky can be imaged?

Resolution
How much detail can be captured?



Resolution

What is the smallest feature that a lens can resolve?

The resolution as an angle on the **sky** is determined by the lens diameter, but the resolution on the image **sensor** is determined by the *f*-number.

The size in μm of the smallest feature on the sensor is $\approx \frac{2}{3} f$

(See the next slides in the handout for how this is calculated)

Maths Warning! Derivation of Resolution

The resolution as an angle on the **sky** is given by :

$$\theta = \frac{1.22\,\lambda}{D}$$

where θ is the angular resolution, λ is the wavelength of light, and D is the diameter of the lens. This is the Rayleigh criterion, derived from the physics of how light waves behave.

The resolution Δ on the image **sensor** is found by multiplying θ by the focal length *FL* :

$$\Delta = \frac{1.22\,\lambda\,FL}{D} = 1.22\,\lambda\,f$$

Maths Warning! Derivation of Resolution

Taking $\lambda \approx 550$ nm (the middle of the visible spectrum) gives :

$$\Delta = 1.22 \times 550\text{nm} \times f = 670\,f \quad [\text{in nm}]$$
$$= 0.67\,f \quad [\text{in } \mu\text{m}]$$

Note that this result will be slightly different for Hα solar scopes ($\lambda = 656$ nm) and for telescopes working at infrared wavelengths.

Resolution

The size in μm of the smallest feature on the sensor is $\approx \frac{2}{3} f$.

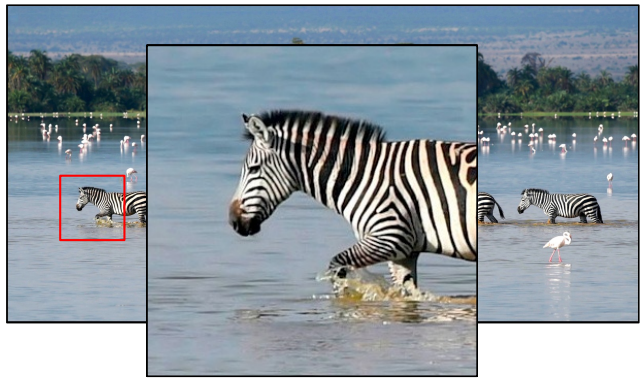
We want to capture all of the detail that the lens can resolve, so what is the 'best' size for the sensor pixels?

The following slides show why pixels that are either too big or too small are not ideal.

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Pixel Size

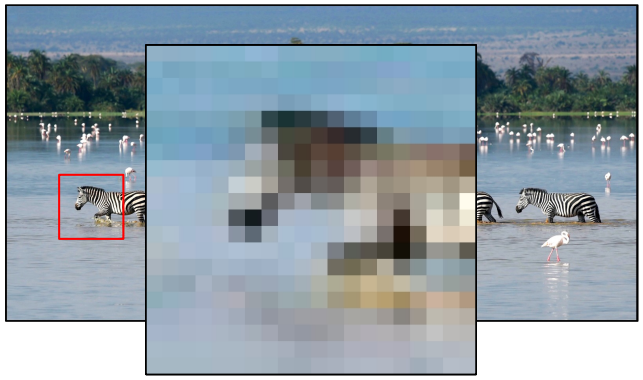


4μm pixels

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Pixel Size



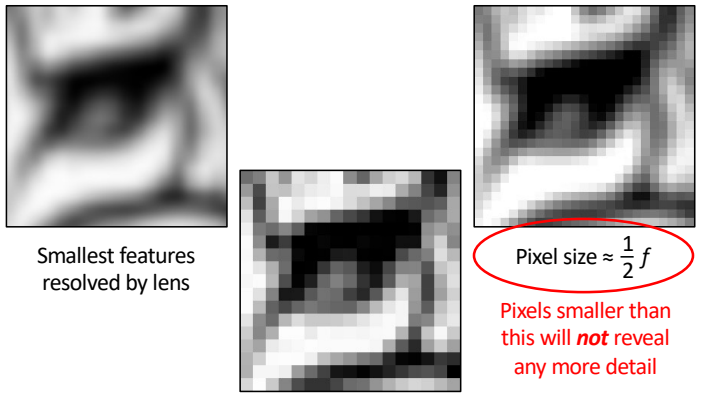
64μm pixels x 16

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Pixel Size



Pixel Size

Thus the optimum pixel size for a given telescope is $\approx \frac{1}{2}f$.

Does this really simple 'rule of thumb' work in practice?

Try it ...

For smart telescopes with $f \approx 5$ the optimum pixel size is 2.5 μm.
The actual pixels sizes are typically 2.9 μm. ✓

For the Hubble Space Telescope (FL=57 m, D=2.4 m, f=24) the optimum pixel size is 12 μm. The pixel size in WFC3 is 10 μm. ✓

Even at these extremes, the "half f" rule works well.

Example

Optics
Focal length and f-number

Sensors
Chip size and Pixel size



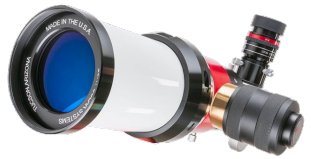
Field of View
How much sky can be imaged?

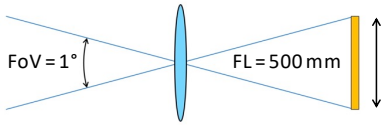
Resolution
How much detail can be captured?



Example

What's the best camera to use with the Lunt LS60T Hα solar telescope?





⇒ sensor size = 9 mm

D = 60 mm, f = 8.3, resolution = 6.7 μm ⇒ pixel size = 4 μm

Example

What's the best camera to use with the Lunt LS60T Hα solar telescope?



From the specs of various cameras, a good match is ...

ZWO ASI 533

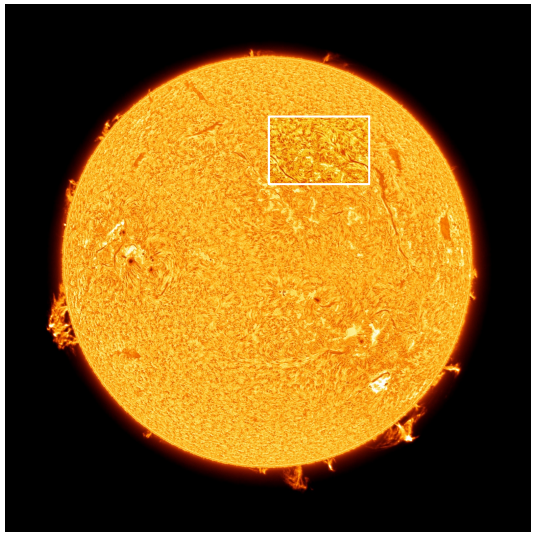
Sensor size = 11 x 11 mm, pixel size = 3.8 μm



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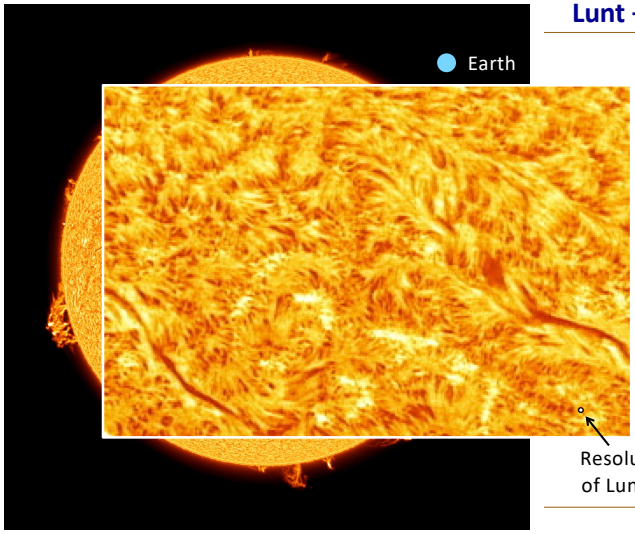
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Lunt + ZWO



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Lunt + ZWO



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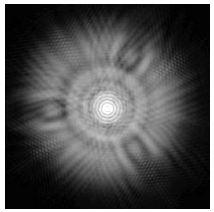
Appendix: Resolution Limits

The resolution of a telescope defined by the Rayleigh criterion is the **best** that can be achieved – a fundamental limit due to the diffraction of light waves in the telescope.

It is not the **worst** than can be achieved.



Ideal star image



HST spherical aberration

If the telescope optics suffer from aberration (such as the Hubble Space Telescope primary mirror) then the resolution will suffer.

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Appendix: Resolution Limits

Resolution can also suffer due to bad **seeing**.

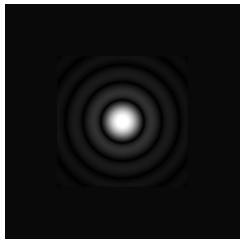
Seeing is image distortion due to turbulence of the atmosphere, which depends on many factors such as temperature gradients and local topography.

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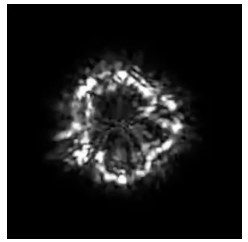
Appendix: Resolution Limits

Ideal star image



The apparent size is determined by the physics of diffraction

Real star image



The star is defocussed to make the effects of bad seeing more obvious

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Appendix: Resolution Limits

So is there any point in a sensor having small pixels if images are always distorted by the atmosphere?

Yes. The highest-resolution images of the Sun, Moon and planets can be achieved with small pixels by employing **lucky imaging**.

Take lots of images in quick succession and later decide which of the images were lucky enough to catch the atmosphere when it was momentarily steady. Throw the rest away.

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