Minimum Detection Limit for telescope-filter-camera system

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Minimum Detection Limit

(from Janesick)

Recall that the signal to noise ratio of a signal-limited image sensor is:

$$\left[\frac{\mathrm{S}}{\mathrm{N}}\right]_{\mathrm{A\_FF}} = \frac{S_{\mathrm{A}}}{[\sigma^2_{\mathrm{READ}} + S_{\mathrm{A}} + (S_{\mathrm{A}}P_{\mathrm{N}})^2]^{1/2}}, \tag{12.1}$$

where $[\mathrm{S/N}]_{\mathrm{A\_FF}}$ is the absolute flat-field S/N performance, and

$$S_{\mathrm{A}} = LN_{\mathrm{L}}t_{\mathrm{I}}\mathrm{QE}_{\mathrm{I}}P_{\mathrm{A}}T_{\mathrm{L}}[4f\#^2(1+m)^2]^{-1}, \tag{12.2}$$

which is the absolute signal (e^-), where $f\#$ and m are the f number and magnification of a lens above the imager, T_{L} is the transmission of the lens, L is the luminance light level emitted from a Lambertian diffuse surface that overfills the collection lens (or detector if a lens is not used) given in lux, and N_{L} is the number of photons/cm^2-sec for one lux. For example, the number of photons at a 0.550-μm wavelength (green) for one lux is 4.02×10^{11} photons/cm^2-sec. Discussions below assume this wavelength to be a standard.

Minimum Detection Limit Cont'd

Minimum detectable sensitivity is defined when S/N = 1, i.e., from Eq. (12.1):

$$1 = \frac{S_A}{[\sigma^2_{READ} + S_A + (S_A P_N)^2]^{1/2}}. \tag{12.4}$$

The illumination level for this condition is derived by first writing Eq. (12.4) into quadratic form as

$$1 = (P_N^2 - 1)S_A^2 + S_A + \sigma^2_{READ}. \tag{12.5}$$

Since $P_N^2 \ll 1$, Eq. (12.5) simplifies to

$$S_A^2 - S_A - \sigma^2_{READ} = 0. \tag{12.6}$$

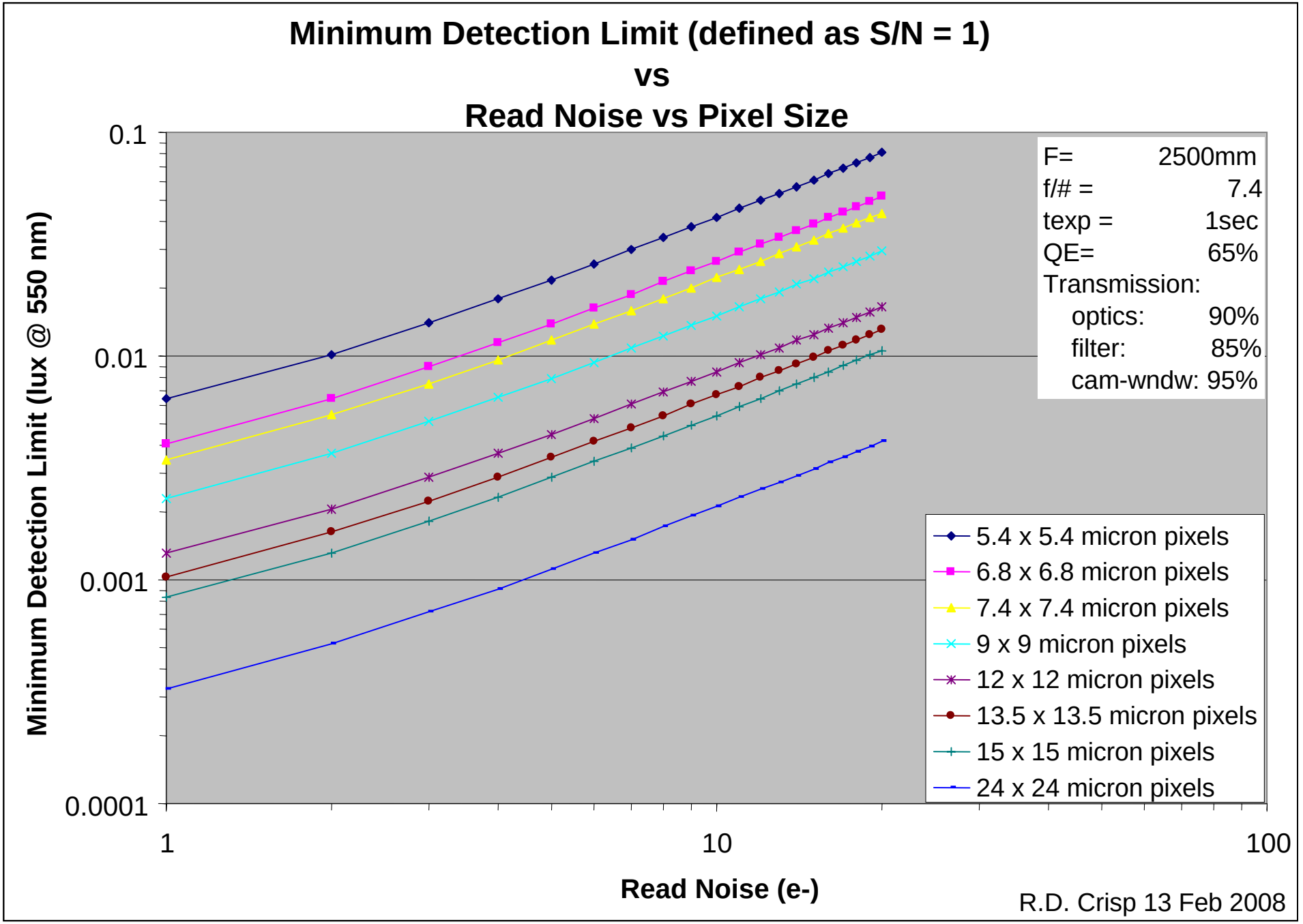
Solving for a positive signal yields

$$S_{A\_MIN} = \frac{1 + (1 + 4\sigma^2_{READ})^{1/2}}{2}, \quad \text{S/N} = 1, \tag{12.7}$$

where S_{A_MIN} is the absolute signal level for S/N = 1.

Substituting S_{A_MIN} into Eq. (12.2) and solving for the amount of lux yields

$$L_{MIN} = \frac{S_{A\_MIN}}{N_L t_I QE_I P_A T_L [4f\#^2(1+m)^2]^{-1}}, \tag{12.8}$$


Minimum Detection Limit (defined as S/N = 1)
vs
Read Noise vs Pixel Size
Minimum Detection Limit (lux @ 550 nm)
0.1
0.01
0.001
0.0001
1
10
100
Read Noise (e-)
F= 2500mm
f/# = 7.4
texp = 1sec
QE= 65%
Transmission:
optics: 90%
filter: 85%
cam-wndw: 95%
5.4 x 5.4 micron pixels
6.8 x 6.8 micron pixels
7.4 x 7.4 micron pixels
9 x 9 micron pixels
12 x 12 micron pixels
13.5 x 13.5 micron pixels
15 x 15 micron pixels
24 x 24 micron pixels
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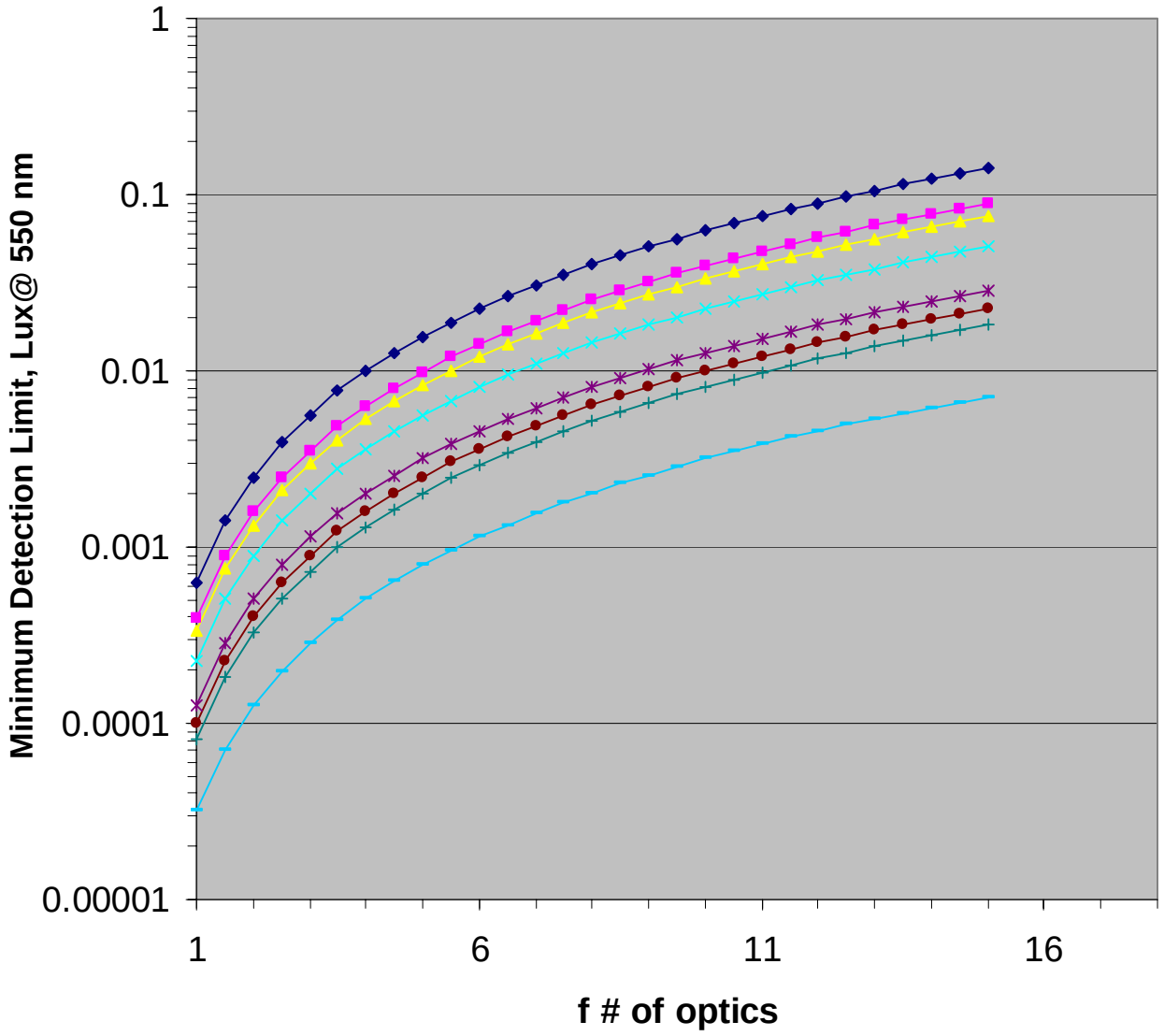
Minimum Detection Limit (Lux @ 550nm)



F= 1220mm
Read Noise = 8 e-
texp = 1sec
QE= 65%
Transmission:
optics: 90%
filter: 85%
cam-wndw: 95%

- 5.4 x 5.4 micron pixels
- 6.8 x 6.8 micron pixels
- 7.4 x 7.4 micron pixels
- 9 x 9 micron pixels
- 12 x 12 micron pixels
- 13.5 x 13.5 micron pixels
- 15 x 15 micron pixels
- 24 x 24 micron pixels

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