Camera Selection Criteria

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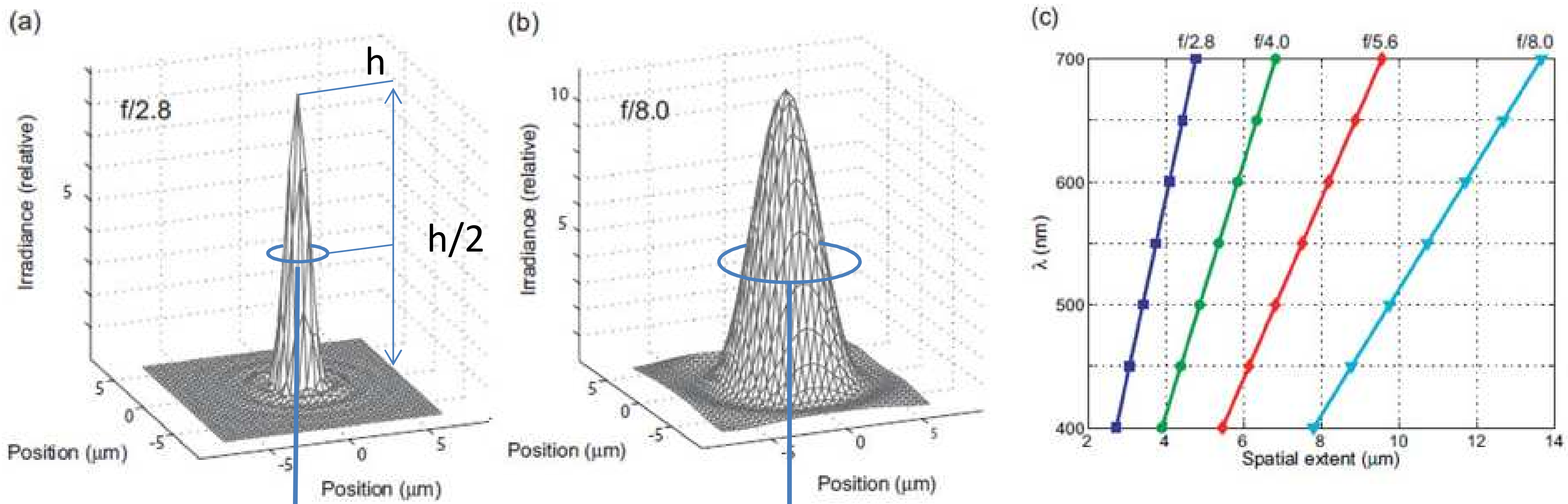
Pixel Size

Pixel size considerations

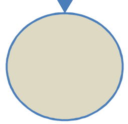
- Key issues are
  - matching the pixel size to the expected spot size from the optical system
  - understanding the relationship among pixel size , optics and rate at which signal builds

Optics and the Airy Disk:
Focal ratio: Sets spot size for diffraction limited optics

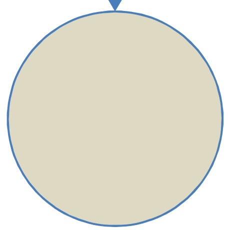


Airy Disk Diameter (microns)

Source: Catrysse



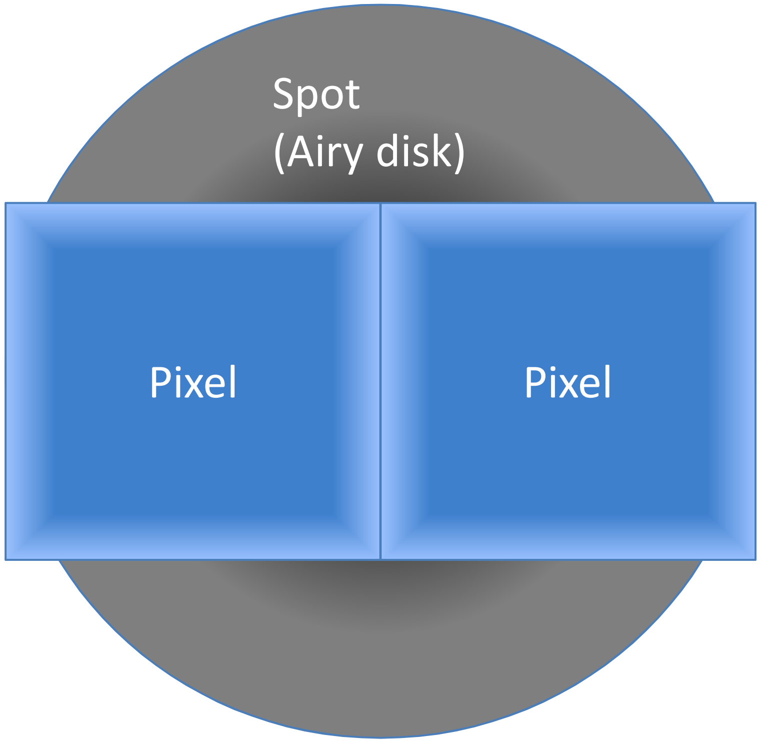
Airy Disk Diameter



~3 microns, f/2.8

~10 microns, f/8.0

Nyquist Sampling of Airy Disk
Pixel Pitch: Sized to fit Airy Disk (spot):



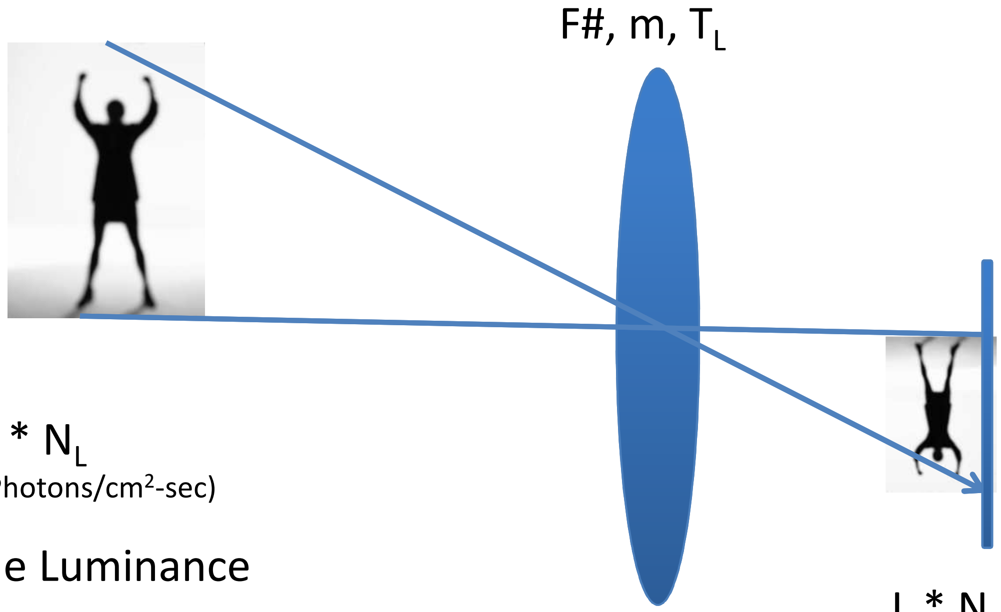
Nyquist Sampling Criteria:

$$Pixel\ size = 1.22 * \lambda * F\#$$

550 nm test wavelength			
Monochrome pixel size (microns)	Optimum F#	Airy Diameter (microns)	Optical resolution: LP/mm
0.75	1.12	1.5	667
0.9	1.34	1.8	556
1	1.49	2	500
1.1	1.64	2.2	455
1.25	1.86	2.5	400
1.4	2.09	2.8	357
1.5	2.24	3	333
1.75	2.61	3.5	286
2	2.98	4	250
2.25	3.35	4.5	222
2.5	3.73	5	200
2.75	4.10	5.5	182
3	4.47	6	167
3.5	5.22	7	143
4	5.96	8	125
5	7.45	10	100
5.4	8.05	10.8	93
6	8.94	12	83
6.8	10.13	13.6	74
7.4	11.03	14.8	68
9	13.41	18	56
11	16.39	22	45
12	17.88	24	42
13.5	20.12	27	37
18	26.83	36	28
24	35.77	48	21

- Exact Nyquist Sampling: 2 pixels to cover Airy Diameter (spot)

Delivering photons to the sensor: the impact of Imaging Lens F# and magnification



m = magnification

= 2*pixel_size*F#/Focal_length

T_L = Transmission of Optics

N_L= photons/cm^2-sec/lux

L=Luminance level (lux)

$L * N_L$

(Photons/cm^2-sec)

Scene Luminance

$$L * N_L \frac{T_L}{4 * F\#^2 * (1+m)^2}$$

(Photons/cm2-sec)

Incident Luminance at Sensor

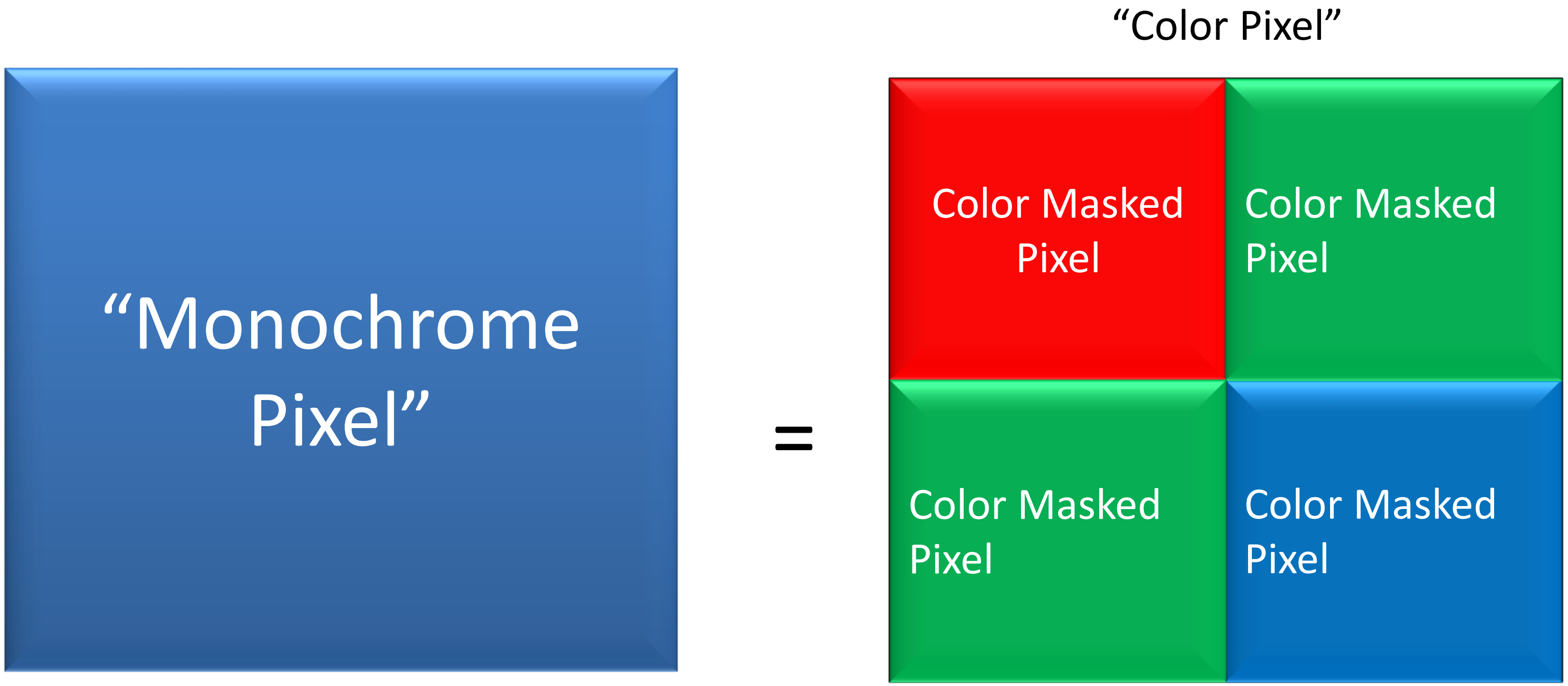
<u>How much does the lens spread the light flux? (magnification)</u>

Color or Monochrome

Monochrome or Color?

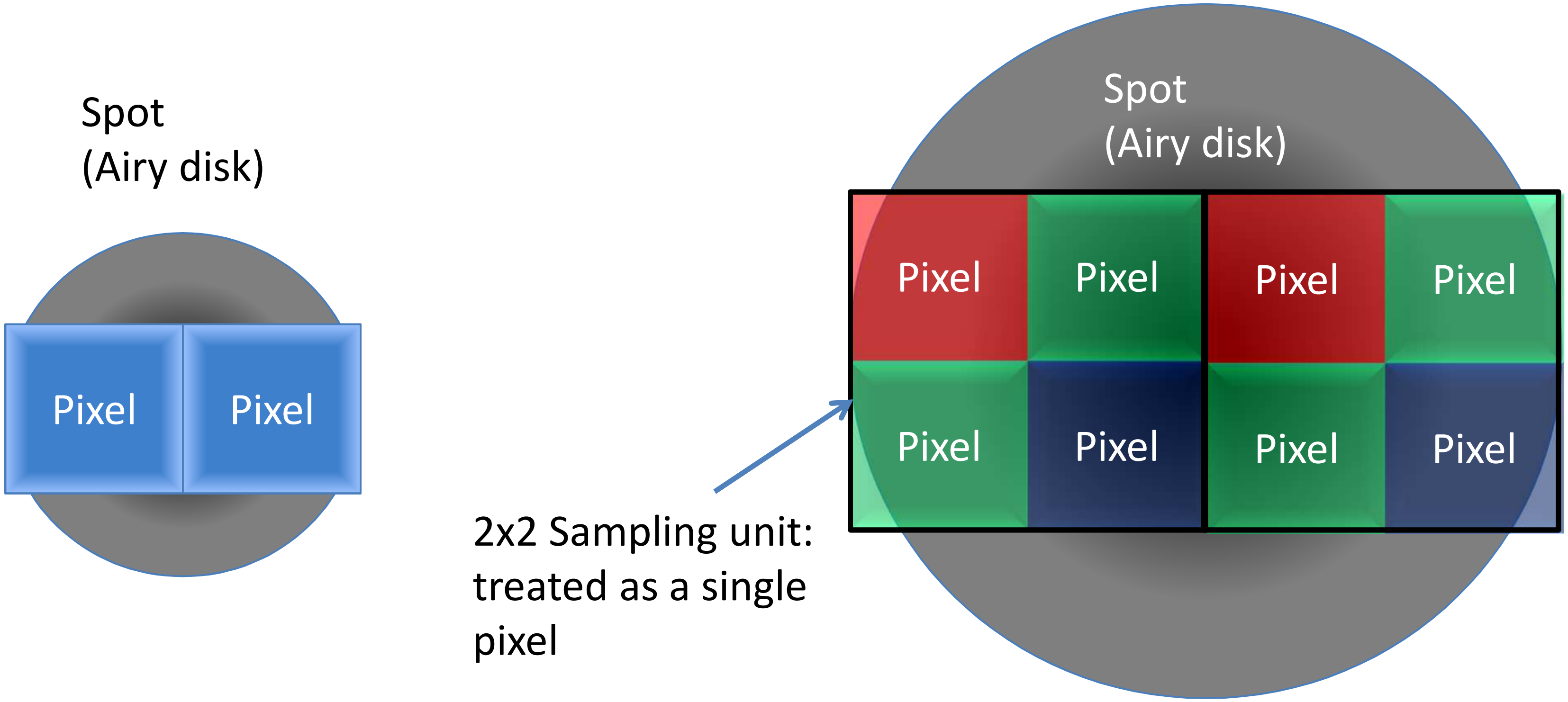
- Monochrome sensors have higher QE across the spectrum
- They can be used with filters, color or emission line, to make color images
- Require multiple sequential exposures through multiple filters to make color image
- Highest level of flexibility
- Transient and fast moving events such as Jupiter, Comets and Star Trails can present challenges for monochrome sensors; the object moves between filter changes
- Daytime/terrestrial color photography challenges
  - Need for filter changes with potential for motion in scene (trees moving etc)
- Color sensors can solve the transient event problem
- But have limitations:
  - Lower final image resolution than monochrome for a given photosite count
  - On chip Color Filter Array (CFA) typically leaks NIR, needs an IR-Cut filter. Typically those foul the red response for Halpha and [SII]
  - Extra image processing required: Must be deinterlaced and color interpolated to “fill in the missing data” (only ½ of the green pixels are “real”, while ¼ of the red and blue pixels are “real”)
  - Less efficient to use with emission line filters

What changes for color imaging?



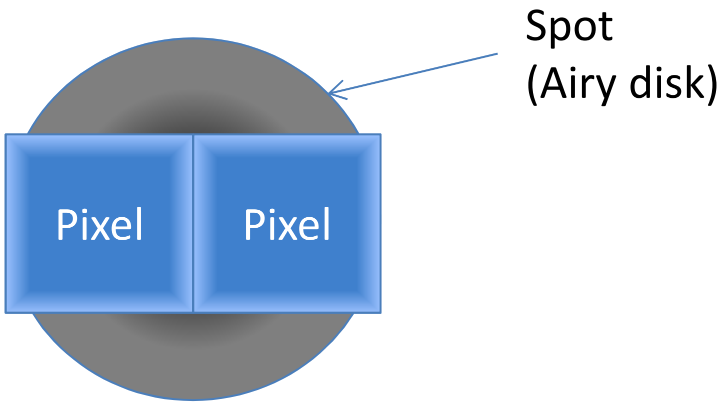
Marketing will call this four pixels
Sampling theory treats the four-pixel unit as one pixel

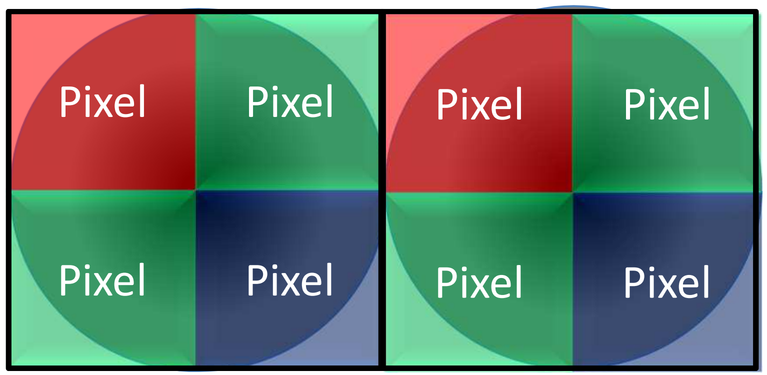
Color Masked Pixels vs Monochrome Pixels: optimum spot size, F# changes



- **Same sensor base pixel size: different optimum spot size**
  - 2:1 difference in optimum F# when using color
  - 2:1 difference in LP/mm required by optics when using color

Color Masked Pixels used on same optics: Undersampled (resolution loss vs mono)



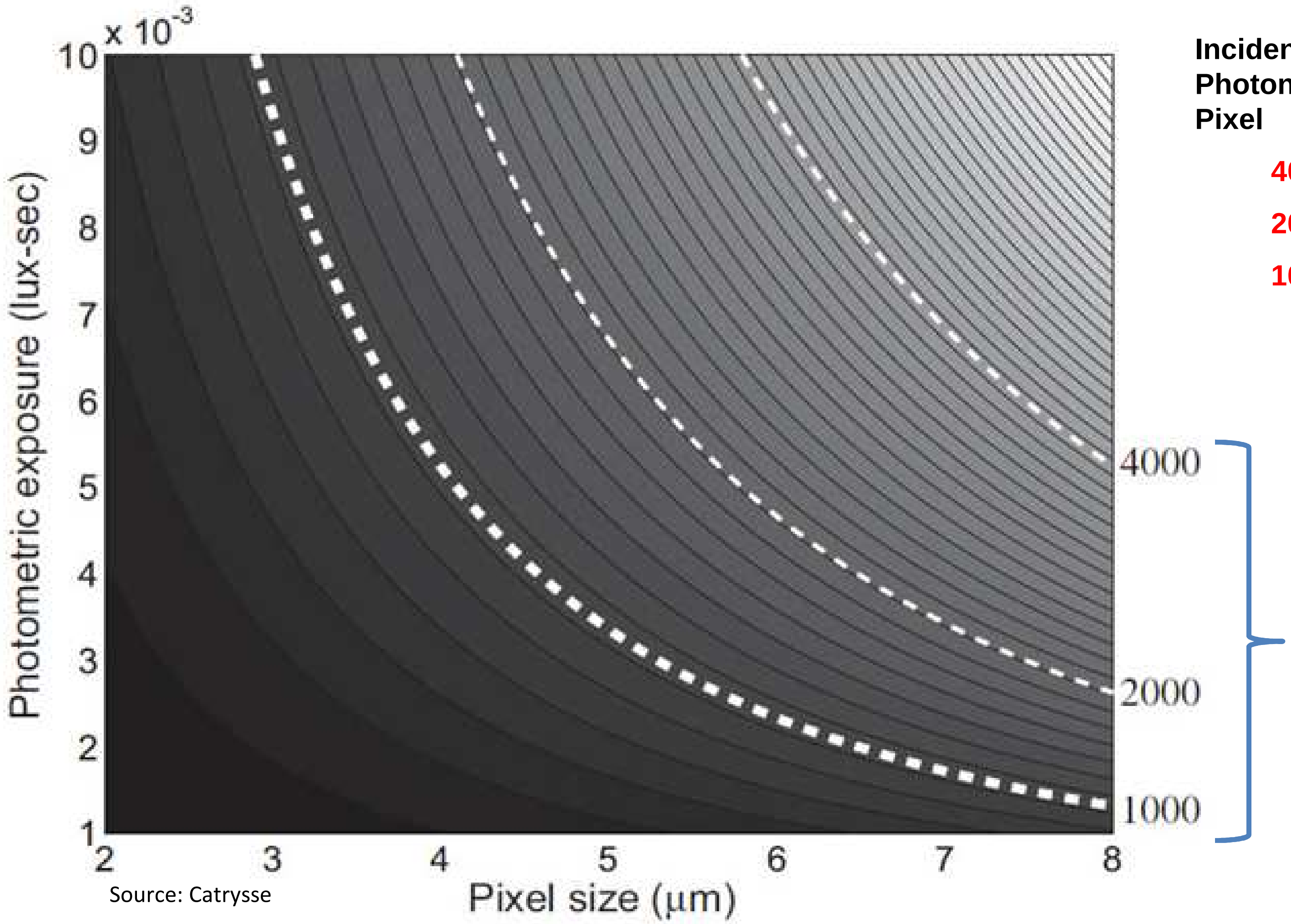


Color sequential monochrome

One shot color

SNR considerations

Pixel Geometry:
How many photons is your pixel receiving?



Source: Catrysse

Photons

Incident Photons/ Pixel	Maximum Theoretical SNR*
4000	63.25
2000	44.72
1000	31.62

*occurs when:
QE= 100%
Noise = 1e-
No fpn
No dark shot
No dark fpn

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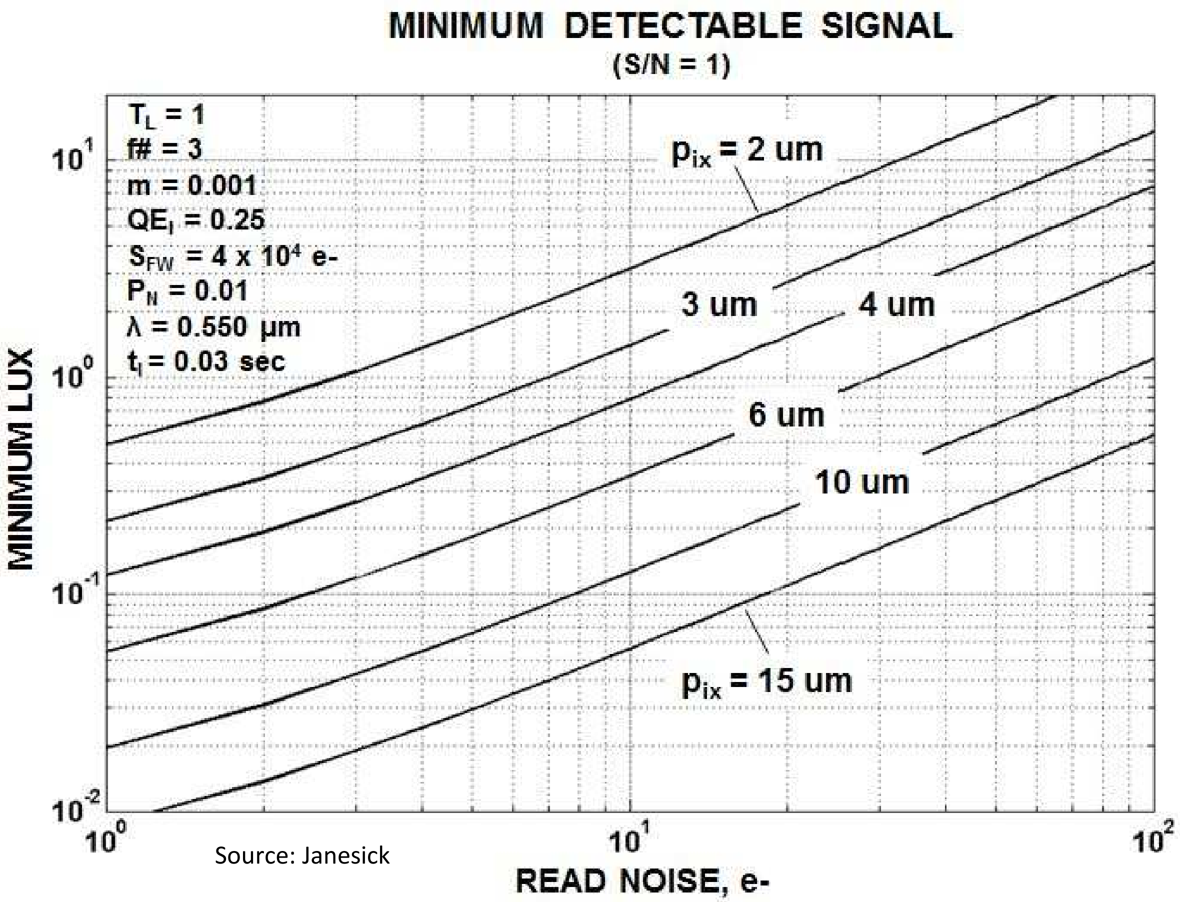
Sensitivity vs Pixel size considering system noise impact



Source: Janesick

100% optical transmission
f/3 optics
Lens magnification of 0.001*
QE = 25%
Full well = 40Ke-
PRNU = 1%
550nm wavelength
Exposure time = 30msec

* For magnification of 0.001, something that is 10 mm tall will fill a 10 micron pixel
ie: a lens that makes a 10 x 10 meter FOV fill a 1000 x 1000 pixel sensor with 10 micron pixel size

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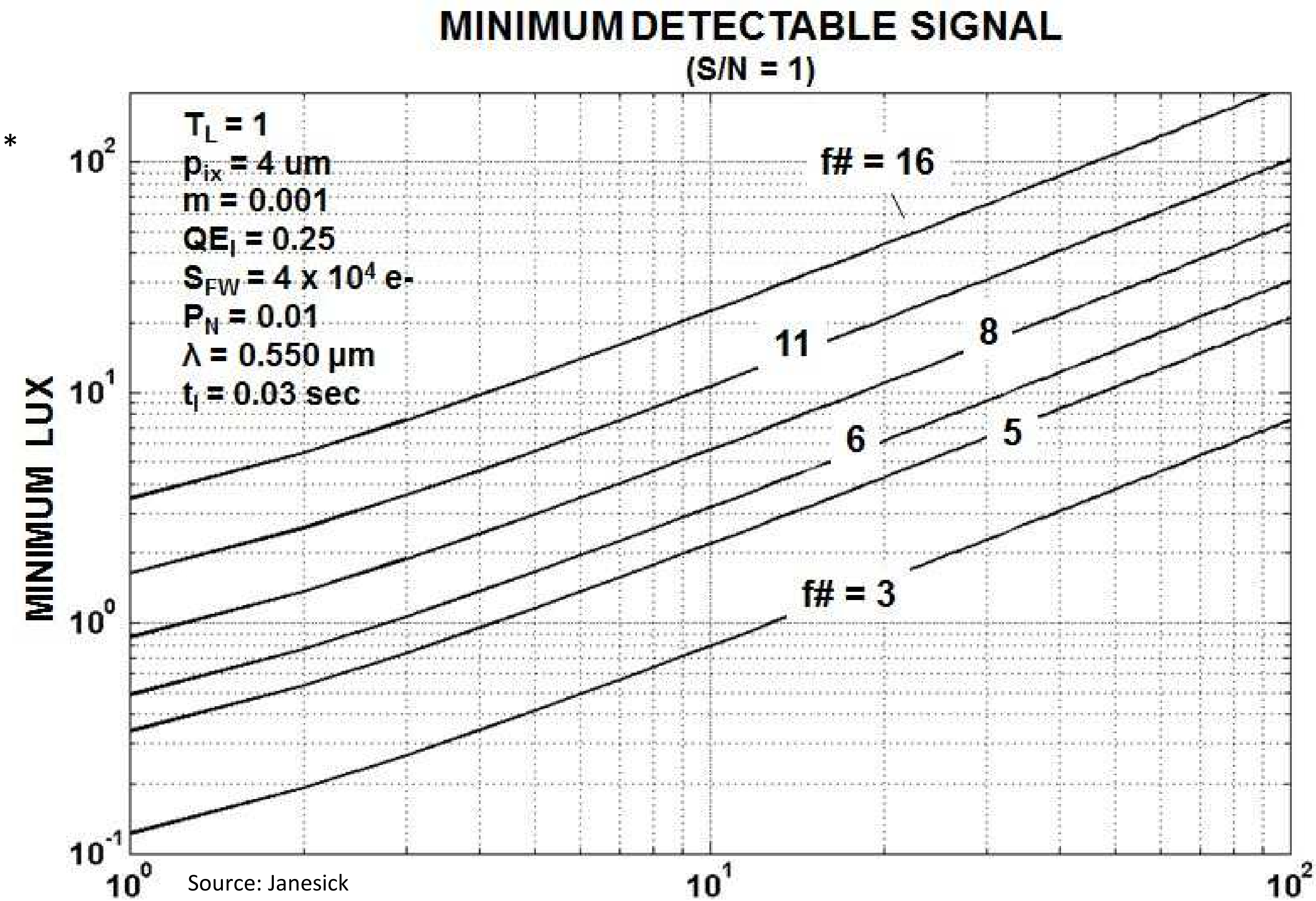
F#, system noise impact

100% optical transmission
4 micron pixel
Lens magnification of 0.001*
QE = 25%
Full well = 40Ke-
PRNU = 1%
550nm wavelength
Exposure time = 30msec



Source: Janesick

Read Noise (e-)

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