## **Radiometry and Photometry for Autonomous Vehicles and Machines - Fundamental Performance Limits**

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#### Abstract

As autonomous vehicles and machines, such as self-driving cars, agricultural drones and industrial robots, become ubiquitous, there is an increasing need to understand the objective performance of cameras to support these functions. Images go beyond aesthetic and subjective roles as they assume increasing aspects of control, safety, and diagnostic capabilities. Radiometry and photometry are fundamental to describing the behavior of light and modeling the signal chain for imaging systems, and as such, are crucial for establishing objective behavior.

As an engineer or scientist, having an intuitive feel for the magnitude of units and the physical behavior of components or systems in any field improves development capabilities and guards against rudimentary errors. Back-of-the-envelope estimations provide comparisons against which detailed calculations may be tested and will urge a developer to "try again" if the order of magnitude is off for example. They also provide a quick check for the feasibility of ideas, a "giggle" or "straight-face" test as it is sometimes known.

This paper is a response to the observation of the authors that, amongst participants that are newly relying on the imaging field and existing image scientists alike, there is a general deficit of intuition around the units and order of magnitude of signals in typical cameras for autonomous vehicles and the conditions within which they operate. Further, there persists a number of misconceptions regarding general radiometric and photometric behavior. Confusion between the inverse square law as applied to illumination and consistency of image luminance versus distance is a common example.

The authors detail radiometric and photometric model for an imaging system, using it to clarify vocabulary, units and behaviors. The model is then used to estimate the number of quanta expected in pixels for typical imaging systems for each of the patches of a MacBeth color checker under a wide variety of illumination conditions. These results form the basis to establish the fundamental limits of performance for passive camera systems based both solely on camera geometry and additionally considering typical quantum efficiencies available presently. Further a mental model is given which will quickly allow user to estimate numbers of photoelectrons in pixel.

#### Introduction

For imaging scientists and camera engineers, anyone working with images as an input to a neural network or computer vision algorithm, or producing simulations with which to train these algorithms, light and its subsequent detection, fundamentally bound the space of engineering solutions to which we have access to. It dictates how many photons can illuminate a surface from a source and consequently the upper bound on the number that could be captured by an imaging system. In combination with imaging system parameters, it absolutely dictates the signal-to-noise ratio an image may have. And while we may apply image processing to improve the appearance of images, it is not possible to add information after the capture stage.

Given how fundamental the behavior of light and cameras are to the profession, there appears to be a number of areas of confusion between the behavior of light and imaging coupled with a general fear of radiometry and photometry. As examples, the authors have heard the comment that "[Images of] lights get darker the further from a camera they are." as a misinterpretation of the inverse square law. Also measuring "lux at the camera" rather than at the target being imaged. Finally, an observation that there is a general lack of intuition for the magnitudes of signals for typical imaging systems in the autonomous vehicle and machines field.

There are a number of excellent texts that deal with radiometry and photometry in detail, such as that by Boyd[1]. While the topic cannot be covered in great depth within this paper, a basic understanding of radiometry and photometry can be outlined in this primer with intentional simplified nomenclature and give readers tools with which to elucidate a first-order model of a source, target and camera for typical automotive systems. The model may be then used to estimate the number of quanta expected in pixels for various imaging systems for each of the patches of a MacBeth color checker and typical automotive lights under a wide variety of illumination conditions. These results form the basis to establish the fundamental limits of performance for passive camera systems based both solely on camera geometry and additionally considering typical quantum efficiencies and noise performance available presently.

The uncertainty surrounding radiometry and photometry can be summed up in one question which we will answer later in the paper. Figure 1(a), depicts a relatively straightforward scenario. Under clear weather and 10 lux ambient daylight, we are tasked with estimating the number of photoelectrons gathered in a 2.1um pixel from a car that has 20% reflective paint (Patch 22 from a MacBeth Color Checker), 100 meters from the camera. The camera has an f1.4 lens with perfect transmission. The sensor has perfect quantum efficiency between 400 and 700nm and is exposed for 10 ms. Figure 1(b) depicts the same scenario expect that the car is at 200m instead of 100m. Without reaching for a calculator or a text book, the authors challenge the reader to estimate the correct number (or even magnitude) of photoelectrons gathered by the pixel for both scenarios. Do you feel at a lost to answer this? Or do you have an idea of how to go about it but feel an urge to reach for that calculator? By the end of the paper you will be able to estimate this without a calculator. Some basic knowledge of light, lenses and imaging sensors is assumed.

#### Photometry and Radiometry

Photometry and radiometry both describe the measurement of the electromagnetic radiation. Radiometry may be applied to the entire electromagnetic spectrum regardless of whether it is seen or not by the eye and encompasses wavelengths from far below  $0.01 \mu m$  to in excess of  $1000 \mu m$ .



Figure 1(a) and (b). A 20% reflective car is imaged in clear weather with an exposure time of 10ms, in 10 lux ambient light with an f1.4 lens. The lens has no transmission loss and the quantum efficiency of the sensor is perfect. How many photoelectrons are generated in a  $2.1 \mu m$  pixel at 100m and 200m?

Photometry examines light that is perceived by the human eyes. Therefore, measurements are restricted to those wavelengths that are visible for the average human eye, about  $0.36\mu$ m to  $0.76\mu$ m by scaling spectral measurements with curves that describe the relative response of the eye at each wavelength, the luminous efficacy or V( $\lambda$ ) curve, Figure 2 [2, p39]. As may be seen, under daylight or photopic conditions, V( $\lambda$ ) peaks at 555nm. The peak shifts to 507nm under scotopic or dark conditions due to adaption of the eye and the reliance on rods, rather than cones to perform imaging.



Figure 2. Spectral luminous efficiency functions under photopic (in black) and scotopic (in red) visions [2, p39].

Therefore, two parallel systems of quantities were developed for radiometry and photometry in the International Systems of Units (SI units). Radiometric measurements and units yielding results that are scaled in purely physical dimensions, such as Watts, and photometric measurements yielding units that also have physical meaning, but are scaled to account for the human eye, such as lumens. For every radiometric unit there is an equivalent photometric unit. Some of the more commonly used units are detailed below.

Due to the above, radiometry and photometry are generally applied in different applications. Radiometry is often used in areas where information concerning the absolute energy of the light is required such as astronomy, solar energy, lasers, and optoelectronics etc. Also, for applications working with wavelengths beyond the visible range, such as night vision, body and eyeball tracking, or LiDARs operating with IR light sources. Photometry is applied in the areas where light perception is the main concern such as lighting, colorimetry, and display technology. It is especially important to note that wavelengths of light beyond the perception of the human eye can still cause great damage to it and therefore radiometric calculations are more appropriate for eye safety.

#### **Point Sources**

Radiant flux ( $\Phi$ ), also referred as power, is radiant energy transferred per unit time. In Figure 3, radiant flux of the light source, the bulb, which we imagine to be a point source, is the total energy that is radiated from the bulb into all directions (the yellow halo surround) per second. The SI unit of radiant flux is the Watt which is equivalent to joules per second (J/s).

A portion of the energy emitted by the bulb may be intercepted by the area A. As the bulb emits equally in all directions, if we can calculate the proportion of the area of the surface of the sphere upon which area A lies, we may calculate the radiant flux that it will receive. In a similar manner that an angle defines a section of a circle in two dimensions, a solid angle defines a section of a sphere and is given the unit steradians (sr). The solid angle,  $\Omega$ , subtended by an area, A is calculated using,

$$\Omega = \frac{A}{r^2} \tag{1}$$

where r is the radius of the circle. Similarly to a circle having 360 degrees, a sphere has a total of  $4\pi$  steradians. Given the distance between the bulb and the surface, the area of the surface and the radiant flux of the source,  $\Phi_B$ , we can now calculate the energy,  $\Phi_A$ , received by A,



Figure 3. Schematics of optical radiation measurement quantities. The measurement plane (with area A) is normal to the bulb light source with subtended solid angle  $\Omega_A$ . The total radiant flux emitted by the bulb is  $\Phi_B$ . The radiant intensity,  $|_B$ , is therefore  $\Phi_B/\Omega_A$  and the total flux received by A,  $\Phi_A=|_B \times \Omega_A$ . The irradiance of A is therefore  $E=\Phi_A/A$ .

If we have the total radiant flux emitted by the source equally in all directions,  $\Phi_B$ , and we divide it by the solid angle into which it radiates, a sphere or  $4\pi$  in the above case, we may calculate the radiant intensity (I) in units of Watts per steradian. Understanding the radiant intensity, I, that a source emits in a particular direction and the solid angle,  $\Omega$ , that a surface subtends to the source allows us to calculate the total energy received by the surface if it is perpendicular to it. In our example above,

$$\Phi_A = I_B \Omega \tag{3}$$

where I<sub>B</sub> is the radiant intensity of the source. The area A has a finite area and receives total flux,  $\Phi_A$ . We may calculate the Irradiance (E) as the radiant flux per unit area received by a surface orthogonal to the source. The irradiance at the measurement plane in Figure 3 is calculated as:

$$E = \frac{\Phi_A}{A} \tag{4}$$

and has units Watt per square meter.

#### Extended sources

Up to this point we have described a point source of light. In practice few sources of electromagnetic radiation are point sources and this should be accounted for in our measurements. Imagine that instead of a single point source we now have many point sources arranged next to each other all radiating in the same direction with the same radiant intensity, Figure 4. If the distance between the area A and the source is large enough that the solid angle between each of the point sources and the area is the same we could simple add up all of the point sources in a unit source area to yield the radiant flux falling on area A. Considering the extension of point sources in this manner we introduce term Radiance (L), or radiant flux per unit area per unit solid angle, with units of Watts per m<sup>2</sup> per sr.

In the example below, if the source has a radiance, L<sub>s</sub>, of 5  $Wm^{-2}sr^{-1}$  and an area, A<sub>s</sub> of  $0.1m^{2}$  and the target an area of  $0.25m^{2}$  and is 2 meters from the target, the radiant flux falling on the target is calculated as in the following manner. The solid angle of target is given by,

$$\Omega_T = \frac{0.25}{2^2} = \frac{0.25}{4} = \frac{1}{16} \,\mathrm{sr.} \tag{5}$$

The total flux falling on Target A is therefore calculated as,

$$\Phi_A = L_S A_S \Omega_T = 5 \times \frac{1}{10} \times \frac{1}{16} = \frac{1}{32}$$
 Watts. (6)

As the area of the target is  $0.25m^2$ , the irradiance is:

$$E = \frac{\Phi_A}{A} = \frac{\frac{1}{32}}{\frac{1}{4}} = \frac{1}{8} \,\mathrm{Wm^{-2}} \tag{7}$$

Area A



#### Spectral measurements and photometry

Total power emitted or received by a source or a surface has been discussed in the previous measurements. We could conduct all of these measurements for individual wavelengths of the electromagnetic spectrum. The radiant flux would become a graph of the energy in Watts per unit wavelength versus wavelength emitted by the source. The radiant intensity would become Watts per steradian per unit wavelength versus wavelength. Doing this we usually adopt the naming convention of spectral intensity, or spectral irradiance.

Measuring these types of quantities for each wavelength allows the scaling of results by the response of the human visual system, as mentioned previously, Figure 2, and thus allows for the estimation of the effect of sources on the human eye. These scaled responses yield equivalent photometric units for each of the radiometric units, Table 1. Photometry is important as it allows for the calculation of the perceived effect of sources on the human visual system. A Watt of light at 555nm at the peak sensitivity of the eye has a very different effect to that at 8 or 12 $\mu$ m in the far infra-red portion of the spectrum that we cannot see. Formally, the conversion from radiant flux to luminous flux,  $\Phi_V$ , is expressed as [1, p102]:

$$\Phi_V = K_m \int \Phi(\lambda) \cdot V(\lambda) \, d\lambda \tag{8}$$

Where the subscript V generally denotes photometric quantities.  $V(\lambda)$  is the spectral luminous efficiency function or the normalized spectral sensitivity of averaged human eye. The unit of  $\Phi_V$  is the lumen (lm) and  $K_m$  is the maximum luminous efficacy.  $K_m$  is 683 lm W<sup>-1</sup> for photopic vision at 555nm and 1700 lm W<sup>-1</sup> for scotopic vision at 510nm [2, p261]. Luminous intensity is the equivalent of radiant intensity and has the units of lumens per steradian, also known as candelas. Irradiance has the equivalent photometric equivalent of Illuminance and units of lumens per meter squared, also known as lux. Radiance is Luminance in its photometric form and has units of lumens per meter squared per steradian. Luminous intensity in candelas is usually used to define this and thus luminance usually takes the units of candelas per meter squared.

Table 1. Photometry an	d radiometry o	quantities
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Quantity	Radiometry (SI unit)	Photometry (SI unit)
Power	Radiant flux (Watt, W)	Luminous flux (lumen, lm)
Power per solid angle	Radiant intensity (W sr <sup>-1</sup> )	Luminous intensity (candela=lm sr <sup>-1</sup> )
Power per unit area	Irradiance, radiant exitance (W m <sup>-2</sup> )	Illuminance, luminous exitance (lux = lm m <sup>-2</sup> )
Power per solid angle per unit area	Radiance (W m <sup>-2</sup> sr <sup>-1</sup> )	Luminance (cd m <sup>-2</sup> )

#### Lambertian Surfaces

If reflected radiance is independent of viewing angle a surface is said to be Lambertian. That is, the Watts per steradian per square meter is approximately constant with respect to angle of viewing in radiometric units and likewise lumens per steradian per square meter in photometric units. This leads to the brightness of a Lambertian surface appearing approximately similar from all viewing angles. Matte white paper is a good approximation to a Lambertian surface [1] as is the MacBeth Color Checker Classic chart. A simple relationship exists between the illuminance and luminance for Lambertian surfaces that make them particularly amenable to working with [3, p16]:

$$L_V = \frac{RE_V}{\pi},\tag{9}$$

where R is reflectance,  $E_v$ , the illuminance and  $L_v$ , the luminance. Alternatively, the luminance is simply the lux falling on the surface multiplied by the reflectance and divided by  $\pi$ . For example, to estimate the luminance in cdm<sup>-2</sup> coming from the 8% patch (Patch 23) of the MacBeth Color Checker Classic, it is simply,

$$L_V = \frac{0.08 \times E_V}{\pi}.\tag{10}$$

#### The inverse square law

Irradiance (or illuminance) from a point source is inversely proportional to the square of the distance from the source. This is the inverse square law. The decrease of irradiance with distance as  $1/r^2$  can be shown as below. Substituting equation 4 into equation 3 we find,

$$E = \frac{I_B \Omega}{A} \tag{11}$$

and then equation 1 into 11,

$$E = \frac{I_B}{A} \cdot \frac{A}{r^2} = \frac{I_B}{r^2}.$$
(12)

The irradiance of a light falling onto a surface diminishes according to the square of the distance. It should also be noticed that they are no other terms in the denominator. Regardless of the radiant intensity or solid angle subtended by the source, it still obeys the inverse square law. Practically, high- or low-beam head lamps with narrow or wide beams will still diminish as the square of the distance.

#### Image Luminance Constancy

The inverse square law is often confused with principles governing the formation of images and it is often thought that the image luminance of objects decreases with increasing distance between the camera and the object. In the absence of atmospheric effects this is not the case and it may be shown that image luminance remains constant with distance. Richardson details an approachable description of the mathematics [4]. Figure 5 illustrates a camera of focal length, f, imaging an object at distance r. The apparent area of the pixel, A<sub>P</sub>, projected into object space may be calculated using similar triangles as [4]:

$$A_P = x' \cdot y' = \frac{x \cdot y \cdot r^2}{f^2}$$
(13)

where x and y are the dimension of the pixel and x', y' are the projected dimensions. The solid angle of the lens,  $\Omega_L$ , of diameter, d, is [4]

$$\Omega_L = \frac{\pi d^2}{4r^2}.$$
(14)

If the luminance of the source is  $L_S$ , and the size of the source extends beyond the area of the projected pixel, the luminance in the pixel,  $L_P$ , is given by:

$$L_P = L_S A_P \Omega_L t_o t_a \tag{15}$$

where  $t_0$  and  $t_a$  are the transmission of the optics and atmosphere respectively. Substituting equations 13 and 14 into the above we find:

$$L_P = L_S \frac{xyr^2}{f^2} \frac{\pi d^2}{4r^2} t_o t_a$$
(16)

The r<sup>2</sup> terms are cancelled and we note that  $\frac{d^2}{f^2}$  is the reciprocal of f-number, f#, yielding:

$$L_P = \frac{L_S xy \pi t_o t_a}{4f^{\#^2}}.$$
(17)

It may be seen in Equation 17 that there is no dependency on distance, r, aside from atmospheric attenuation,  $t_a$ . Thus, image luminance stays constant with distance in the absence of atmospheric effects. In practice, the amount of light imaged for the object does decrease with distance, but the size of the image of an object also decreases, keeping the image luminance constant with distance. It is worth emphasizing that this applies equally to self-luminous sources or reflected surfaces.

If for the question posed at the beginning of the paper you wrote different answers for 1(a) and 1(b) you may wish to reconsider.



Figure 5, A simple model of a lens and pixel imaging a surface. Based on [4].

#### Illumination, Target, Lens, Sensor Model

The information given in the previous sections may be used to create an illumination - target – lens - sensor model that will give good first order approximations of the number of photoelectrons collected in pixel for given conditions from simple Lambertian reflectors orthogonal to the optical axis. The model is modified from that previously been detailed by Jenkin and Kane [5]. The desired ambient light level is first specified in lux,  $E_{AMB}$ , to scale a CIE D55 spectral curve,  $W(\lambda)$ , representing the illumination source [5]. The relative spectral luminous efficiency curve,  $V(\lambda)$ , of the CIE is scaled by the peak luminous efficiency of human vision (683 lumens per watt at 555 nm) [2, p261], multiplied by the D55 curve above and integrated to yield the total lux,  $W(\lambda)$  represented by the illumination curve generated:

$$E_{SOURCE} = 683. \int_{\lambda_{MIN}}^{\lambda_{MAX}} W(\lambda) V(\lambda) d\lambda$$
(18)

where  $\lambda_{MAX}$  and  $\lambda_{MIN}$  are the maximum and minimum wavelengths of interest.  $E_{AMB}$  is divided by  $E_{SOURCE}$  to yield a multiplication factor,  $E_{SCALE}$ , by which to multiply  $W(\lambda)$  so that it is correctly scaled to the wattage required to yield the lux desired in the scene.

The spectral reflectance curve of the target surface  $S(\lambda)$  is multiplied by the scaled illumination curve and divided by  $\pi$  to give the spectral radiance of the surface in Wm<sup>-2</sup>sr<sup>-1</sup>nm<sup>-1</sup>. Further multiplying by the absolute quantum efficiency curve of the sensor,  $Q(\lambda)$ , and absolute transmission of an infrared filter,  $I(\lambda)$ , yields the spectrum of light available to the sensor in Wm<sup>-2</sup>sr<sup>-1</sup>nm<sup>-1</sup> before lens and pixel geometry are considered,  $P(\lambda)$ , below.

$$P(\lambda) = \frac{E_{SCALE}}{\pi} W(\lambda) S(\lambda) I(\lambda) Q(\lambda)$$
(19)

In this model CIE D55 is used as the illumination spectra, shown in Figure 6 [2, p271]. The Macbeth Color Checker Classic patches are used as target spectra, Figure 7 [6]. Quantum efficiency curves are created by first modelling a typically monochrome curve peaking at approximately 83% and then multiplying that with those representing transmissions for red, green, blue, yellow, magenta and cyan color filter arrays, Figure 8 [7].



Figure 6, Relative Spectral Power of CIE D55 illumination [2, p271].

This intentionally does not represent any single sensor available at present but is a good approximation of current performance and quantum efficiency curves representing actual sensors may easily be substituted if necessary. The solid angle,  $\Omega_l$ , of the lens collecting the signal reflected from the projected pixel area is calculated using equation 14. Multiplying by the solid angle and transmission of the lens, *to*, yields the power per nm per square meter, *P*<sub>s</sub>, captured by the sensor:

$$P_{s}(\lambda) = \frac{E_{SCALE}}{\pi} W(\lambda) I(\lambda) Q(\lambda) \Omega_{L} t_{o}$$
<sup>(20)</sup>

A factor for losses due to windshield transmission may also be included in  $t_0$ . Multiplying by the area of the pixel,  $A_p$ , yields the power per nm per pixel,  $P_p$ .

$$P_p(\lambda) = \frac{E_{SCALE}}{\pi} W(\lambda) I(\lambda) Q(\lambda) \Omega_L t_o. A_p$$
(21)

The energy per photon,  $\varepsilon(\lambda)$ , is calculated using:

$$\varepsilon(\lambda) = \frac{hc}{\lambda} \tag{22}$$

where *h* is Plank's constant, 6.62x10-34 m<sup>2</sup> kg s<sup>-1</sup>, and *c* is the speed of light, 299792458 ms<sup>-1</sup>. Dividing  $P_p(\lambda)$  by  $\varepsilon(\lambda)$ , multiplying by the integration time,  $T_{INT}$ , and integrating yields the total number of photoelectrons captured by the pixel,  $PE_p$ :

$$PE_p = \int_{\lambda_{MIN}}^{\lambda_{MAX}} \frac{T_{INT}.P_p(\lambda)}{\varepsilon(\lambda)} d\lambda$$
(23)

The above model represents a relatively simple single exposure regime. By repeating calculations with different exposure times or adding an attenuation term, it is relatively simple to extend the model to estimate photoelectrons collected for sequential or other high dynamic range exposure (HDR) schemes.

It should also be noted that the surface modeling here only accounts for diffusely lit Lambertian patches orthogonal to the optical axis of the camera. Specular and retroreflective materials with different lighting geometries will yield different results.



Figure 7, Spectral reflectance of the MacBeth Color Checker Classic patches [6].

#### Imaging Performance for typical parameters

Using the above model, it is possible to estimate photoelectrons per lux-second at the sensor plane for D55 daylight and the MacBeth color chart for a variety of conditions, pixel sizes and CFA filters, Table 2. Calculated for an f1.4 lens, the first row, "Geo", represents the photons available if only the geometry of the imaging is considered between 400 and 700nm. The aperture f1.4 is chosen as it represents the leading edge of what is available in automotive manufacturing at present. No losses due to lens transmission, IRCF, windshield or quantum efficiency are added. This represents the maximum amount of light available to the sensor for conversion into signal and gives a fundamental envelope of performance in this wavelength range.



Figure 8, Quantum efficiency curves of each of the color channels created using data for CFA filter materials [7]. Also shown is the IRCF transmission curve used.

If the data for Patch 22 is examined, we can see that approximately 1000 photons are generated per lux-second for a 2um pixel with D55 at f1.4. The reflectance of the patch is approximately 18.7% between 400 and 700nm [6]. Using this as a starting point we can create a mental model to estimate the photons available to a sensor for other conditions. Rounding the reflectance of patch 22 to 20% we can state "Patch 22 (20%) for  $2\mu m$  at  $f\sqrt{2}$ gives 1 photon per lux per ms". This can then be modified to yield other results. A stop in any direction will double or halve the result. e.g f2 will give 0.5 photons per lux per ms. Photons will be proportional to pixel area. Doubling the pixel size will yield four times the number of photons. For automotive purposes it is then possible to add in degradation to account for lens transmission (0.95), IRCF transmission (0.95 between 400 and 650nm), windshield losses (0.7) and the color filter array. For a monochrome array the available signal is approximately 0.4x when the above losses and silicon sensitivity are factored in. For RGB CFAs this drops to between 0.1x (Red) and 0.15x (Green) and for CMY CFAs 0.2x (Magenta) to 0.25x (Yellow). Finally, for 2.1 µm pixels, as this is a common node, we can add 10%.

While far from perfect, this approach gives engineers a starting point with which to estimate the order of magnitude of a signal available from a pixel. Using our car example, Figure 1(a) which calls for estimating the signal from 10lux daylight using an f1.4 lens and  $2.1\mu m$  pixel with a 10ms exposure in clear conditions with no losses from a 20% reflective surface. We start with the mental model "20% f $\sqrt{2}$  (f1.4) at with a 2 $\mu$ m pixel gives 1 photon per ms". For 10ms at 10 lux this would yield 100 photons. Add 10% to uprate to a 2.1 $\mu$ m pixel modifies our estimate to 110 photons. If we wanted to estimate signal in the green channel after losses, we further multiply by 0.15 = 16 photons. Performing the actual calculation with the model yields 119 and 17 photons. The estimate is well within an order of magnitude of the actual result.

Further examining Table 2, we observe that imaged photons are somewhere between 10% and 25% of the available photons once losses due to the lens, windshield, IRCF and quantum efficiency are accounted for. While losses in any one process may

appear manageable, it is worth remembering that they are multiplicative and quickly collapse the available signal envelope. It is also worth noting that the effective sensitivity of the system is a fraction of the 10's of thousands of electrons per lux-second for sensitivity usually quoted by sensor manufacturers. This is because sensitivity measurements are often made by directly illuminating the sensor and do not account for lens geometries, surface reflectance or other system losses.

Signal variance due to the quantized nature of light, or shot noise as it is known, is equal to the number of quanta present. Therefore, using RMS fluctuations (the square root of the number of quanta) to calculate signal-to-noise ratio due to shot noise, we find it is directly proportional to the size of the pixel. Total SNR, however, includes a fixed noise component of a few electrons, consisting of a number of contributors, such a read noise, dark signal non-uniformity and dark current. As these components are signal independent and generally increase with temperature, they quickly dominate signal-to-noise performance at low light levels.

Table 3 shows photoelectrons for a D55 5lux 10ms exposure with a f1.4 aperture. If we wish to achieve a linear SNR of 1 and the fixed noise component is a total of 3 electrons RMS at least 3.5 photoelectrons of signal are required. For a linear SNR of 4, in excess 22.4 photoelectrons are needed. Examining Table 3 we can see that at 5 lux, all but the brightest Macbeth patches at the 2.1 $\mu$ m node with a CFA applied struggle to achieve the desired number of photoelectrons for an SNR of 4. We conclude, that for the modelled system, below 5 lux we will rapidly approach the noise floor of the sensor and should expect the system performance to degrade significantly.

#### Summary

A primer of basic radiometry and photometry was outlined and used to construct an elementary model of an illumination source, Lambertian surface, lens and sensor with the intention of giving engineers new to the field or those already working with cameras an introduction to the subject. The imaging model was used to illustrate how it is possible to establish fundamental performance limits for an imaging system. A mental model was also offered that can yield first order approximations of photoelectrons in pixel for typical quantum efficiencies and system losses available at present.

#### References

- [1] R. W. Boyd, Radiometry and the Detection of Optical Radiation, Rochester, New York: John Wiley and Sons Inc., 1982.
- [2] R. W. G. Hunt, Measuring Color, 2<sup>nd</sup> Ed., London: Ellis Horwood Limited, 1995.
- [3] M. A. Richardson et al, Surveillance and Target Acquisition Systems, 2<sup>nd</sup> Ed., London: Brassey's (UK) Limited, 1997.
- [4] M. A. Richardson, "Electro-Optical Systems Analysis Part 2" Journal Battlefield Technol., vol. 5, no. 3, p. 21, 2002.
- [5] R. Jenkin and P. Kane, "Fundamental Imaging System Analysis for Autonomous Vehicles", Proc. IS&T Electronic Imaging, Autonomous Vehicles and Machines 2018, Burlingame, California, 2018.
- [6] BabelColor, https://www.babelcolor.com/colorchecker.htm, Last accessed June 2021.
- [7] Fuji Film (United States) Corporation, https://www.fujifilm.com/us/en/business/semiconductor-

materials/image-sensor-color-mosaic/cmy/applications, Last accessed June 2021.

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## Table 2. Photoelectrons per lux-second for a f1.4 lens imaging diffusely lit MacBeth Color Checker patches with CIE D55 illumination.

	Patch	Numbe	r 1 - Da	ark Skir	e		Patch	Numbe	r 2 - Lip	t Skin			Patch	Numbe	er 3 - Bl	lue Sky			Patch	Numb	er 4 - F	oliage		F	Patch N	umber	5 - Blue	e Flowe	er	F	atch N	umber	6 - Blui	ish Gree	en
Px Sz	1	2	2.1	2.25	3	Px Sz	1	2	2.1	2.25	3	Px Sz	1	2	2.1	2.25	3	Px Sz	1	2	2.1	2.25	3	Px Sz	1	2	2.1	2.25	3	Px Sz	1	2	2.1	2.25	3
Geo	164	658	725	833	1480	Geo	553	2213	2439	2800	4978	Geo	263	1053	1161	1333	2369	Geo	147	586	646	742	1319	Geo	437	1749	1928	2214	3936	Geo	484	1935	2134	2449	4354
Mono	45	178	196	225	401	Mono	168	673	742	852	1515	Mono	111	445	490	563	1001	Mono	51	204	225	258	459	Mono	148	593	654	751	1335	Mono	201	805	888	1019	1812
Red	19	75	83	95	169	Red	65	260	286	329	584	Red	19	77	85	97	173	Red	13	53	58	67	119	Red	32	130	143	165	292	Red	33	133	147	169	300
Grn	16	62	69	79	141	Grn	61	244	269	308	548	Grn	41	165	182	209	372	Grn	24	97	107	123	218	Grn	51	204	224	258	458	Grn	90	361	398	457	812
Ble	10	39	43	49	88	Ble	42	167	184	211	376	Ble	48	190	210	241	428	Ble	12	47	52	60	106	Ble	62	248	274	314	559	Ble	71	284	313	360	639
Cyn	20	79	87	100	178	Cyn	83	330	364	418	743	Cyn	78	312	344	395	702	Cyn	29	114	126	145	257	Cyn	99	397	438	503	894	Cyn	138	551	607	697	1239
Mgn	27	107	118	135	240	Mgn	99	396	436	501	890	Mgn	61	245	271	311	552	Mgn	23	93	102	117	209	Mgn	87	349	384	441	785	Mgn	95	381	420	482	857
Ylw	33	133	147	169	300	Ylw	122	486	536	616	1095	Ylw	57	228	251	289	513	Ylw	38	153	169	194	344	Ylw	77	310	341	392	697	Ylw	124	495	546	627	1114
	Patch	Numb	er 7 - C	Drange		P	atch N	umber	8 - Purp	olish Blu	e	Patch	Numbe	r 9 - M	oderate	e Red			Patch	Numbe	r 10 - I	Purple		Pa	atch Nu	mber 1	1 - Yell	ow Gre	en	Pa	tch Nu	mber 1	2 - Orai	nge Yel	llow
Px Sz	1	2	2.1	2.25	3	Px Sz	1	2	2.1	2.25	3	Px Sz	1	2	2.1	2.25	3	Px Sz	1	2	2.1	2.25	3	Px Sz	1	2	2.1	2.25	3	Px Sz	1	2	2.1	2.25	3
Geo	451	1803	1988	2282	4056	Geo	219	877	967	1110	1974	Geo	411	1646	1814	2083	3703	Geo	163	653	720	826	1469	Geo	438	1752	1932	2218	3943	Geo	569	2277	2510	2882	5123
Mono	119	476	524	602	1070	Mono	90	361	398	457	812	Mono	104	414	457	524	932	Mono	45	182	200	230	409	Mono	156	626	690	792	1408	Mono	164	658	725	832	1479
Red	67	270	297	341	606	Red	13	51	56	64	114	Red	59	237	261	299	532	Red	12	50	55	63	111	Red	45	182	200	230	409	Red	79	314	347	398	707
Grn	39	158	174	200	355	Grn	29	114	126	144	257	Grn	27	106	117	134	239	Grn	13	52	57	65	116	Grn	78	313	345	397	705	Grn	64	257	283	325	577
Ble	12	47	52	60	106	Ble	47	189	209	239	426	Ble	21	83	91	105	186	Ble	19	77	85	97	173	Ble	27	106	117	134	239	Ble	18	74	82	94	166
Cyn	34	135	148	170	303	Cyn	69	276	304	349	621	Cyn	36	145	160	184	326	Cyn	28	114	125	144	256	Cyn	80	320	353	405	720	Cyn	57	227	251	288	512
Mgn	74	298	328	377	670	Mgn	55	219	241	277	493	Mgn	75	300	331	380	675	Mgn	30	119	132	151	269	Mgn	67	268	295	339	603	Mgn	91	365	402	462	821
Ylw	104	418	460	529	940	Ylw	36	143	157	180	321	Ylw	79	317	350	402	714	Ylw	23	92	101	116	206	Ylw	129	516	569	654	1162	Ylw	143	572	630	724	1287
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	Patc	h Numb	ber 13 -	- Blue			Patch	n Numb	er 14 -	Green		24	Patc	h Num	ber 15	- Red			Patch	Numbe	r 16 -	rellow			Patch P	Number	17 - N	lagenta	3		Patc	h Numi	ber 18 -	- Cyan	
Px Sz	Patcl	h Numb 2	2.1	- Blue 2.25	3	Px Sz	Patch 1	2 Numb	2.1	Green 2.25	3	Px Sz	Patc 1	h Num 2	2.1	- Red	3	Px Sz	Patch 1	2	2.1	2.25	3	Px Sz	Patch P	2	2.1	2.25	3	Px Sz	Patc 1	h Numb	2.1	- Cyan 2.25	3
Px Sz Geo	Patc 1 134	2 537	2.1 592	- Blue 2.25 679	<b>3</b> 1207	Px Sz Geo	Patch 1 202	2 807	2.1 890	Green 2.25 1021	3 1816	Px Sz Geo	Patc 1 361	h Num 2 1446	2.1 1594	- Red 2.25 1830	<b>3</b> 3253	Px Sz Geo	1 719	2 2875	2.1 3169	2.25 3638	<b>3</b> 6468	Px Sz Geo	1 504	2 2016	2.1 2223	2.25 2552	<b>3</b> 4537	Px Sz Geo	Patc 1 267	2 1067	2.1 1177	2.25	<b>3</b> 2401
Px Sz Geo Mono	Patc 1 134 60	2 537 240	2.1 592 265	- Blue 2.25 679 304	3 1207 540	Px Sz Geo Mono	Patch 1 202 85	2 807 341	2.1 890 376	<b>2.25</b> 1021 431	3 1816 766	Px Sz Geo Mono	Patc 1 361 68	h Num 2 1446 270	2.1 1594 298	- Red 2.25 1830 342	3 3253 608	Px Sz Geo Mono	1 719 221	2 2875 883	2.1 3169 974	2.25 3638 1118	3 6468 1987	Px Sz Geo Mono	1 504 127	2 2016 508	2.1 2223 560	2.25 2552 643	3 4537 1144	Px Sz Geo Mono	Patc 1 267 121	2 1067 485	2.1 1177 535	- Cyan 2.25 1351 614	3 2401 1091
Px Sz Geo Mono Red	Patc 1 134 60 6	2 537 240 25	2.1 592 265 27	- Blue 2.25 679 304 31	3 1207 540 55	Px Sz Geo Mono Red	Patch 202 85 15	2 807 341 59	2.1 890 376 65	Green           2.25           1021           431           75	3 1816 766 133	Px Sz Geo Mono Red	Patc 1 361 68 48	2 1446 270 191	2.1 1594 298 210	- Red 2.25 1830 342 241	3253 608 429	Px Sz Geo Mono Red	Patch 1 719 221 93	2875 883 372	2.1 3169 974 410	2.25 3638 1118 470	3 6468 1987 836	Px Sz Geo Mono Red	1 504 127 56	2 2016 508 224	2.1 2223 560 247	2.25 2552 643 284	3 4537 1144 505	Px Sz Geo Mono Red	Patc 1 267 121 12	1067 485 48	2.1 1177 535 53	Cyan 2.25 1351 614 60	3 2401 1091 107
Px Sz Geo Mono Red Grn	Patc 1 134 60 6 17	2 537 240 25 68	2.1 592 265 27 75	- Blue 2.25 679 304 31 87	3 1207 540 55 154	Px Sz Geo Mono Red Grn	Patch 1 202 85 15 47	2 807 341 59 186	2.1 890 376 65 205	Green           2.25           1021           431           75           236	3 1816 766 133 419	Px Sz Geo Mono Red Grn	Patc 1 361 68 48 14	2 1446 270 191 55	2.1 1594 298 210 61	- Red 2.25 1830 342 241 70	3 3253 608 429 124	Px Sz Geo Mono Red Grn	1 719 221 93 96	2 2875 883 372 384	2.1 3169 974 410 423	2.25 3638 1118 470 486	3 6468 1987 836 863	Px Sz Geo Mono Red Grn	1 504 127 56 31	2 2016 508 224 126	2.1 2223 560 247 139	2.25 2552 643 284 159	3 4537 1144 505 283	Px Sz Geo Mono Red Grn	Patc 1 267 121 12 49	2 1067 485 48 196	2.1 1177 535 53 216	Cyan 2.25 1351 614 60 248	3 2401 1091 107 441
Px Sz Geo Mono Red Grn Ble	Patc 1 134 60 6 17 36	2 537 240 25 68 144	2.1 592 265 27 75 159	- Blue 2.25 679 304 31 87 182	3 1207 540 55 154 324	Px Sz Geo Mono Red Grn Ble	Patch 1 202 85 15 47 20	2 807 341 59 186 78	er 14 - 2.1 890 376 65 205 86	Green           2.25           1021           431           75           236           99	3 1816 766 133 419 176	Px Sz Geo Mono Red Grn Ble	Patc 1 361 68 48 14 9	2 1446 270 191 55 35	2.1 1594 298 210 61 39	- Red 2.25 1830 342 241 70 44	3253 608 429 124 79	Px Sz Geo Mono Red Grn Ble	Patch 1 719 221 93 96 27	2 2875 883 372 384 108	2.1 3169 974 410 423 119	2.25 3638 1118 470 486 137	3 6468 1987 836 863 243	Px Sz Geo Mono Red Grn Ble	1 504 127 56 31 41	2 2016 508 224 126 162	2.1 2223 560 247 139 179	2.25 2552 643 284 159 206	3 4537 1144 505 283 365	Px Sz Geo Mono Red Grn Ble	Patc 1 267 121 12 49 58	2 1067 485 48 196 230	2.1 1177 535 53 216 254	Cyan 2.25 1351 614 60 248 291	3 2401 1091 107 441 518
Px Sz Geo Mono Red Grn Ble Cyn	Patc 1 134 60 6 17 36 49	2 537 240 25 68 144 196	2.1 592 265 27 75 159 217	- Blue 2.25 679 304 31 87 182 249	3 1207 540 55 154 324 442	Px Sz Geo Mono Red Grn Ble Cyn	Patch 202 85 15 47 20 53	2 807 341 59 186 78 211	er 14 - 2.1 890 376 65 205 86 233	Green           2.25           1021           431           75           236           99           267	<b>3</b> 1816 766 133 419 176 475	Px Sz Geo Mono Red Grn Ble Cyn	Patc 1 361 68 48 14 9 16	2 1446 270 191 55 35 64	ber 15 2.1 1594 298 210 61 39 71	- Red 2.25 1830 342 241 70 44 81	3 3253 608 429 124 79 144	Px Sz Geo Mono Red Grn Ble Cyn	Patch 1 719 221 93 96 27 89	2 2875 883 372 384 108 354	2.1 3169 974 410 423 119 391	2.25 3638 1118 470 486 137 448	3 6468 1987 836 863 243 797	Px Sz Geo Mono Red Grn Ble Cyn	1 504 127 56 31 41 61	2 2016 508 224 126 162 245	2.1 2223 560 247 139 179 270	2.25 2552 643 284 159 206 310	3 4537 1144 505 283 365 551	Px Sz Geo Mono Red Grn Ble Cyn	Patc 1 267 121 12 49 58 96	1067 485 48 196 230 384	2.1 1177 535 53 216 254 424	Cyan           2.25           1351           614           60           248           291           487	3 2401 1091 107 441 518 865
Px Sz Geo Mono Red Grn Ble Cyn Mgn	Patc 1 134 60 6 17 36 49 38	2 537 240 25 68 144 196 152	2.1 592 265 27 75 159 217 168	- Blue 2.25 679 304 31 87 182 249 192	3 1207 540 55 154 324 442 342	Px Sz Geo Mono Red Grn Ble Cyn Mgn	Patch 1 202 85 15 47 20 53 32	2 807 341 59 186 78 211 127	er 14 - 2.1 890 376 65 205 86 233 140	Green           2.25           1021           431           75           236           99           267           161	<b>3</b> 1816 766 133 419 176 475 285	Px Sz Geo Mono Red Grn Ble Cyn Mgn	Patc 1 361 68 48 14 9 16 54	2 1446 270 191 55 35 64 217	ber 15 2.1 1594 298 210 61 39 71 239	- Red 2.25 1830 342 241 70 44 81 275	<b>3</b> 3253 608 429 124 79 144 488	Px Sz Geo Mono Red Grn Ble Cyn Mgn	Patch 1 719 221 93 96 27 89 112	2875 883 372 384 108 354 450	2.1 3169 974 410 423 119 391 496	2.25 3638 1118 470 486 137 448 569	3 6468 1987 836 863 243 797 1012	Px Sz Geo Mono Red Grn Ble Cyn Mgn	1 504 127 56 31 41 61 91	2 2016 508 224 126 162 245 366	2.1 2223 560 247 139 179 270 403	2.25 2552 643 284 159 206 310 463	3 4537 1144 505 283 365 551 823	Px Sz Geo Mono Red Grn Ble Cyn Mgn	Patc 1 267 121 12 49 58 96 62	1067 485 48 196 230 384 250	2.1 1177 535 53 216 254 424 276	Cyan 2.25 1351 614 60 248 291 487 316	3 2401 1091 107 441 518 865 562
Px Sz Geo Mono Red Grn Ble Cyn Mgn Ylw	Patc 1 134 60 6 17 36 49 38 18	2 537 240 25 68 144 196 152 73	2.1 592 265 27 75 159 217 168 80	- Blue 2.25 679 304 31 87 182 249 192 92	3           1207           540           55           154           324           442           342           164	Px Sz Geo Mono Red Grn Ble Cyn Mgn Ylw	Patch           1           202           85           15           47           20           53           32           65	2 807 341 59 186 78 211 127 260	er 14 - 2.1 890 376 65 205 86 233 140 287	Green           2.25           1021           431           75           236           99           267           161           329	3 1816 766 133 419 176 475 285 586	Px Sz Geo Mono Red Grn Ble Cyn Mgn Ylw	Patc 1 361 68 48 14 9 16 54 57	2 1446 270 191 55 35 64 217 230	ber 15 2.1 1594 298 210 61 39 71 239 253	- Red 2.25 1830 342 241 70 44 81 275 291	3253 608 429 124 79 144 488 517	Px Sz Geo Mono Red Grn Ble Cyn Mgn Ylw	Patch 1 719 221 93 96 27 89 112 192	2875 883 372 384 108 354 450 769	r 16 - 7 2.1 3169 974 410 423 119 391 496 848	2.25 3638 1118 470 486 137 448 569 974	3 6468 1987 836 863 243 797 1012 1731	Px Sz Geo Mono Red Grn Ble Cyn Mgn Ylw	1 504 127 56 31 41 61 91 80	2016 508 224 126 162 245 366 319	217 - W 2.1 2223 560 247 139 179 270 403 351	2,25 2552 643 284 159 206 310 463 403	3 4537 1144 505 283 365 551 823 717	Px Sz Geo Mono Red Grn Ble Cyn Mgn Ylw	Patc 1 267 121 12 49 58 96 62 58	2 1067 485 48 196 230 384 250 231	2.1 1177 535 53 216 254 424 276 254	- Cyan 2.25 1351 614 60 248 291 487 316 292	3           2401           1091           107           441           518           865           562           519
Px Sz Geo Mono Red Grn Ble Cyn Mgn Ylw Pa	Patcl 1 134 60 6 17 36 49 38 18 tch Nut	240 25 68 144 196 152 73 mber 1	2.1 592 265 27 75 159 217 168 80 9 - Whi	- Blue 2.25 679 304 31 87 182 249 192 92 itte (0.0	3 1207 540 55 154 324 442 342 164 5D)	Px Sz Geo Mono Red Grn Ble Cyn Mgn Ylw Pat	Patch 1 202 85 15 47 20 53 32 65 tch Nur	2 807 341 59 186 78 211 127 260 mber 20	er 14 - 2.1 890 376 65 205 86 233 140 287 - Neu	Green           2.25           1021           431           75           236           99           267           161           329           cral (0.2)	3 1816 766 133 419 176 475 285 586 3D)	Px Sz Geo Mono Red Grn Ble Cyn Mgn Ylw Pa	Patc 1 361 68 48 14 9 16 54 57 cch Nun	2 1446 270 191 55 35 64 217 230 mber 21	ber 15 2.1 1594 298 210 61 39 71 239 253 - Neut	- Red 2.25 1830 342 241 70 44 81 275 291 tral (0.4	3253 608 429 124 79 144 488 517 4D)	Px Sz Geo Mono Red Grn Ble Cyn Mgn Ylw Pat	Patch           1           719           221           93           96           27           89           112           192           ch Nur	2875 883 372 384 108 354 450 769 nber 22	r 16 - 7 2.1 3169 974 410 423 119 391 496 848 - Neut	2.25 3638 1118 470 486 137 448 569 974 rral (0.7	3 6468 1987 836 863 243 797 1012 1731 0D)	Px Sz Geo Mono Red Grn Ble Cyn Mgn Ylw Pat	1 504 127 56 31 41 61 91 80 cch Nun	2016 508 224 126 162 245 366 319 mber 23	217 - W 2.1 2223 560 247 139 179 270 403 351 - Neut	2.25 2552 643 284 159 206 310 463 403 rral (1.0	3 4537 1144 505 283 365 551 823 717 5D)	Px Sz Geo Mono Red Grn Ble Cyn Mgn Ylw	Patc 1 267 121 12 49 58 96 62 58 atch N	2 1067 485 48 196 230 384 250 231 umber	2.1 1177 535 53 216 254 424 276 254 254 24 - Bla	- Cyan 2.25 1351 614 60 248 291 487 316 292 ck (1.5	3 2401 1091 107 441 518 865 562 519 D)
Px Sz Geo Mono Red Grn Ble Cyn Mgn Ylw Pa Px Sz	Patcl 1 134 60 6 17 36 49 38 18 tch Nut 1	h Numb 2 537 240 25 68 144 196 152 73 mber 19 2	2.1 592 265 27 75 159 217 168 80 9 - Whi 2.1	- Blue 2.25 679 304 31 87 182 249 192 92 ite (0.0	3 1207 540 55 154 324 442 342 164 5D) 3	Px Sz Geo Mono Red Grn Ble Cyn Mgn Ylw Pat Px Sz	Patch 1 202 85 15 47 20 53 32 65 tch Nur 1	2 807 341 59 186 78 211 127 260 mber 20 2	er 14 - 2.1 890 376 65 205 86 233 140 287 - Neut 2.1	Green           2.25           1021           431           75           236           99           267           161           329           tral (0.2:           2.25	3 1816 766 133 419 176 475 285 586 3D) 3	Px Sz Geo Mono Red Grn Ble Cyn Mgn Ylw Pa Px Sz	Patc 1 361 68 48 14 9 16 54 57 57 tch Nun 1	2 1446 270 191 55 35 64 217 230 mber 21 2	ber 15 2.1 1594 298 210 61 39 71 239 253 - Neut 2.1	- Red 2.25 1830 342 241 70 44 81 275 291 tral (0.4 2.25	3 3253 608 429 124 79 144 488 517 4D) 3	Px Sz Geo Mono Red Grn Ble Cyn Mgn Ylw Pat Px Sz	Patch           1           719           221           93           96           27           89           112           192           cch Num           1	2 2875 883 372 384 108 354 450 769 mber 22 2	r 16 - 7 2.1 3169 974 410 423 119 391 496 848 - Neut 2.1	2.25 3638 1118 470 486 137 448 569 974 erral (0.7 2.25	3 6468 1987 836 863 243 797 1012 1731 0D) 3	Px Sz Geo Mono Red Grn Ble Cyn Mgn Ylw Pat Px Sz	1 504 127 56 31 41 61 91 80 tch Nun 1	2 2016 508 224 126 162 245 366 319 mber 23 2	2.1 2223 560 247 139 179 270 403 351 - Neut 2.1	2.25 2552 643 284 159 206 310 463 403 rral (1.0 2.25	3 4537 1144 505 283 365 551 823 717 5D) 3	Px Sz Geo Mono Red Grn Ble Cyn Mgn Ylw Px Sz	Patc 1 267 121 12 49 58 96 62 58 atch N 1	2 1067 485 48 196 230 384 250 231 umber 2	2.1 1177 535 53 216 254 424 276 254 254 254 254 24 - Bla 2.1	- Cyan 2.25 1351 614 60 248 291 487 316 292 ick (1.5 2.25	3 2401 1091 107 441 518 865 562 519 D) 3
Px Sz Geo Mono Red Grn Ble Cyn Mgn Ylw Pa Px Sz Geo	Patcl 1 134 60 6 17 36 49 38 18 tch Nut 1 1181	h Numb 2 537 240 25 68 144 196 152 73 mber 19 2 4726	2.1 592 265 27 75 159 217 168 80 9 - Whi 2.1 5210	- Blue 2.25 679 304 31 87 182 249 192 92 ite (0.0 2.25 5981	3 1207 540 55 154 324 442 342 164 5D) 3 10633	Px Sz Geo Mono Red Grn Ble Cyn Mgn Ylw Pat Px Sz Geo	Patch 1 202 85 15 47 20 53 32 65 tch Nur 1 778	2 807 341 59 186 78 211 127 260 mber 20 2 3114	er 14 - 2.1 890 376 65 205 86 233 140 287 - Neut 2.1 3433	Green           2.25           1021           431           75           236           99           267           161           329           tral (0.2           2.25           3941	3 1816 766 133 419 176 475 285 586 3D) 3 7006	Px Sz Geo Mono Red Grn Ble Cyn Mgn Ylw Pa Px Sz Geo	Patc 1 361 68 48 14 9 16 54 57 57 tch Nun 1 477	2 1446 270 191 55 35 64 217 230 mber 21 2 1909	ber 15 2.1 1594 298 210 61 39 71 239 253 - Neut 2.1 2104	- Red 2.25 1830 342 241 70 44 81 275 291 tral (0.4 2.25 2416	3 3253 608 429 124 79 144 488 517 40) 3 4294	Px Sz Geo Mono Red Grn Ble Cyn Mgn Ylw Pat Px Sz Geo	Patch           1           719           221           93           96           27           89           112           192           cch Num           1           271	2 2875 883 372 384 108 354 450 769 nber 22 2 1082	r 16 - 7 2.1 3169 974 410 423 119 391 496 848 - Neut 2.1 1193	2.25 3638 1118 470 486 137 448 569 974 rral (0.7 2.25 1370	3 6468 1987 836 863 243 797 1012 1731 0D) 3 2435	Px Sz Geo Mono Red Grn Ble Cyn Mgn Ylw Pat Px Sz Geo	Patch P           1           504           127           56           31           41           61           91           80           tch Num           1           123	2 2016 508 224 126 162 245 366 319 nber 23 2 493	2.1 2223 560 247 139 179 270 403 351 - Neut 2.1 544	2.25 2552 643 284 159 206 310 463 403 rral (1.0 2.25 624	3 4537 1144 505 283 365 551 823 717 5D) 3 1109	Px Sz Geo Mono Red Grn Ble Cyn Mgn Ylw Px Sz Geo	Patc 1 267 121 12 49 58 96 62 58 atch N 1 45	2 1067 485 48 196 230 384 250 231 231 umber 2 181	2.1 1177 535 53 216 254 424 276 254 254 254 254 254 254 254 254 254 254	- Cyan 2.25 1351 614 60 248 291 487 316 292 ick (1.5 2.25 229	3 2401 1091 107 441 518 865 562 519 <b>D</b> 3 407
Px Sz Geo Mono Red Grn Ble Cyn Mgn Ylw Pa Px Sz Geo Mono	Patcl 1 134 60 6 17 36 49 38 18 18 10 1181 434	Numb 2 537 240 25 68 144 196 152 73 mber 19 2 4726 1735	2.1 592 265 27 75 159 217 168 80 9 - Whi 5210 1913	- Blue 2.25 679 304 31 87 182 249 192 92 ite (0.0 2.25 5981 2196	3 1207 540 55 154 324 442 342 164 5D) 3 10633 3903	Px Sz Geo Mono Red Grn Ble Cyn Mgn Ylw Pat Px Sz Geo Mono	Patch 1 202 85 15 47 20 53 32 65 tch Nur 1 778 287	2 807 341 59 186 78 211 127 260 mber 20 2 3114 1148	er 14 - 2.1 890 376 65 205 86 233 140 287 - Neut 3433 1266	Green           2.25           1021           431           75           236           99           267           161           329           tral (0.2           3941           1454	3 1816 766 133 419 176 475 285 586 3D) 3 7006 2584	Px Sz Geo Mono Red Grn Ble Cyn Mgn Ylw Pa' Px Sz Geo Mono	Patc 1 361 68 48 14 9 16 54 57 tch Nun 1 477 177	2 1446 270 191 55 35 64 217 230 mber 21 230 1909 706	Just 2           1594           298           210           61           39           71           239           253           - Neut           210           210	- Red 2.25 1830 342 241 70 44 81 275 291 tral (0.4 2.25 2416 894	3 3253 608 429 124 79 144 488 517 40) 3 4294 1589	Px Sz Geo Mono Red Grn Ble Cyn Mgn Ylw Pat Px Sz Geo Mono	Patch           1           719           221           93           96           27           89           112           192           ch Num           1           271           100	2 2875 883 372 384 108 354 450 769 nber 22 2 1082 401	r 16 - 7 2.1 3169 974 410 423 119 391 496 848 - Neut 2.1 1193 442	2.25 3638 1118 470 486 137 448 569 974 rral (0.7 2.25 1370 507	3 6468 1987 836 863 243 797 1012 1731 0D) 3 2435 902	Px Sz Geo Mono Red Grn Ble Cyn Mgn Ylw Pat Px Sz Geo Mono	1           504           127           56           31           41           61           91           80           tch Nun           123           46	2 2016 508 224 126 162 245 366 319 nber 23 2 493 183	2.1 2223 560 247 139 179 270 403 351 - Neut 2.1 544 202	2.25 2552 643 284 159 206 310 463 403 rral (1.0 2.25 624 232	3 4537 1144 505 283 365 551 823 717 5D) 3 1109 413	Px Sz Geo Mono Red Grn Ble Cyn Mgn Ylw Px Sz Geo Mono	Patc 1 267 121 12 49 58 96 62 58 atch N 1 45 17	1067 485 48 196 230 384 250 231 umber 2 181 67	2.1 1177 535 53 216 254 424 276 254 254 254 254 254 254 254 254 254 254	- Cyan 2.25 1351 614 60 248 291 487 316 292 3ck (1.5 2.25 229 85	3 2401 1091 107 441 518 865 562 519 D) 3 407 151
Px Sz Geo Mono Red Grn Ble Cyn Mgn Ylw Pa Sz Geo Mono Red	Patcl 1 134 60 6 17 36 49 38 18 18 18 1181 434 115	Numb 2 537 240 25 68 144 196 152 73 mber 19 2 4726 1735 458	2.1 592 265 27 75 159 217 168 80 9 - Whi 5210 1913 505	- Blue 2.25 679 304 31 87 182 249 192 92 ite (0.0 2.25 5981 2196 580	3 1207 540 55 154 324 442 342 164 5D) 3 10633 3903 1031	Px Sz Geo Mono Red Grn Ble Cyn Mgn Ylw Pat Px Sz Geo Mono Red	Patch 1 202 85 15 47 20 53 32 65 tch Nur 1 778 287 76	2 807 341 59 186 78 211 127 260 mber 20 2 3114 1148 302	er 14 - 2.1 890 376 65 205 86 233 140 287 - Neut 2.1 3433 1266 333	Green           2.25           1021           431           75           236           99           267           161           329           cral (0.2:           3941           1454           382	3 1816 766 133 419 176 475 285 586 3D) 3 7006 2584 680	Px Sz Geo Mono Red Grn Ble Cyn Mgn Ylw Pa' Px Sz Geo Mono Red	Patc 1 361 68 48 14 9 16 54 57 tch Nun 1 477 177 46	2 1446 270 191 55 35 64 217 230 mber 21 230 1909 706 185	Just 2           1594           298           210           61           39           71           239           253           - Neut           2104           779           204	- Red 2.25 1830 342 241 70 44 81 275 291 tral (0.4 2.25 2416 894 234	3 3253 608 429 124 79 144 488 517 420 3 4294 1589 416	Px Sz Geo Mono Red Grn Ble Cyn Mgn Ylw Pat Px Sz Geo Mono Red	Patch           1           719           221           93           96           27           89           112           192           cch Num           1           271           100           26	2 2875 883 372 384 108 354 450 769 nber 22 2 1082 401 105	r 16 - 2.1 3169 974 410 423 119 391 496 848 - Neut 2.1 1193 442 116	2.25 3638 1118 470 486 137 448 569 974 448 569 974 <b>2.25</b> 1370 507 133	3 6468 1987 836 863 243 797 1012 1731 0D) 3 2435 902 236	Px Sz Geo Mono Red Grn Ble Cyn Mgn Ylw Pat Px Sz Geo Mono Red	1           504           127           56           31           41           61           91           80           tch Nun           123           46           12	2 2016 508 224 126 162 245 366 319 nber 23 2 493 183 47	2.1 2223 560 247 139 179 270 403 351 - Neut 2.1 544 202 52	2.25 2552 643 284 159 206 310 463 403 403 <b>cral (1.0</b> 2.25 624 232 60	3 4537 1144 505 283 365 551 823 717 5D) 3 1109 413 106	Px Sz Geo Mono Red Grn Ble Cyn Mgn Ylw Px Sz Geo Mono Red	Patc 1 267 121 12 49 58 96 62 58 atch N 1 45 17 4	1067 485 48 196 230 384 250 231 umber 2 181 67 17	2.1 1177 535 53 216 254 424 276 254 254 254 254 21 200 74 19	- Cyan 2.25 1351 614 60 248 291 487 316 291 316 291 316 292 35 229 85 22	3           2401           1091           107           441           518           865           562           519           D)           3           407           151           39
Px Sz Geo Mono Red Grn Ble Cyn Mgn Ylw Pa Sz Geo Mono Red Grn	Patcl 1 134 60 6 17 36 49 38 18 18 18 1181 434 115 169	Numb 2 537 240 25 68 144 196 152 73 mber 19 2 4726 1735 458 678	2.1 592 265 27 75 159 217 168 80 9 - Whi 5210 1913 505 747	Blue 2.25 679 304 31 87 182 249 192 92 ite (0.0 5981 2196 580 858	3 1207 540 55 154 324 442 342 164 5D) 3 10633 3903 1031 1525	Px Sz Geo Mono Red Grn Ble Cyn Mgn Ylw Pat Sz Geo Mono Red Grn	Patch 1 202 85 15 47 20 53 32 65 tch Nur 1 778 287 76 112	2 807 341 59 186 78 211 127 260 mber 20 2 3114 1148 302 446	er 14 - 2.1 890 376 65 205 86 233 140 287 - Neut 2.1 3433 1266 333 492	Green           2.25           1021           431           75           236           99           267           161           329           cral (0.2:           3941           1454           382           565	3 1816 766 133 419 176 475 285 586 3D) 3 7006 2584 680 1004	Px Sz Geo Mono Red Grn Ble Cyn Mgn Ylw Pa' Px Sz Geo Mono Red Grn	Patc 1 361 68 48 14 9 16 54 57 tch Num 1 477 177 46 69	Num           2           1446           270           191           55           35           64           217           230           nber 21           1909           706           185           274	Just 2           1594           298           210           61           39           71           239           253           - Neut           2104           779           204           302	- Red 2.25 1830 342 241 70 44 81 275 291 tral (0.4 2.25 2416 894 234 347	3 3253 608 429 124 79 144 488 517 429 3 4294 1589 416 617	Px Sz Geo Mono Red Grn Ble Cyn Mgn Ylw Pat Geo Mono Red Grn	Patch           1           719           221           93           96           27           89           112           192           cch Num           1           271           100           26           39	2 2875 883 372 384 108 354 450 769 nber 22 1082 401 105 155	<b>2.1</b> 3169 974 410 423 119 391 496 848 <b>- Neut</b> <b>2.1</b> 1193 442 116 171	2.25 3638 1118 470 486 137 448 569 974 ral (0.7 2.25 1370 507 133 197	3 6468 1987 836 863 243 797 1012 1731 0D) 3 2435 902 236 350	Px Sz Geo Mono Red Grn Ble Cyn Mgn Ylw Pat Geo Mono Red Grn	Patch P           1           504           127           56           31           41           61           91           80           tch Nun           1           123           46           12           18	2 2016 508 224 126 162 245 366 319 mber 23 2 493 183 47 71	2.1 2223 560 247 139 179 270 403 351 - Neut 2.1 544 202 52 78	2,25 2552 643 284 159 206 310 463 403 rral (1.0 2.25 624 232 60 90	3 4537 1144 505 283 365 551 823 717 55D 3 1109 413 106 160	Px Sz Geo Mono Red Grn Ble Cyn Mgn Ylw Px Sz Geo Mono Red Grn	Patc 1 267 121 12 49 58 96 62 58 atch N 1 45 17 4 6	2 1067 485 48 196 230 384 250 231 umber 2 181 67 17 26	2.1 1177 535 53 216 254 424 276 254 24 - Bla 200 74 19 29	Cyan 2.25 1351 614 60 248 291 487 316 292 6ck (1.5 229 85 229 85 22 33	3           2401           1091           107           441           518           865           562           519           D)           3           407           151           39           58
Px Sz Geo Mono Red Grn Ble Cyn Mgn Ylw Pa Px Sz Geo Mono Red Grn Ble	Patcl 1 134 60 6 17 36 49 38 18 18 18 1181 434 115 169 140	Number           2           537           240           25           68           144           196           152           73           mber 19           2           4726           1735           458           678           558	2.1 592 265 27 75 159 217 168 80 9 - Whi 5210 1913 505 747 616	Blue           2.25           679           304           31           87           182           249           192           92           ite (0.0           2.25           5981           2196           580           858           707	3 1207 540 55 154 324 442 342 164 5D) 3 10633 3903 1031 1525 1256	Px Sz Geo Red Grn Ble Cyn Mgn Ylw Pat Px Sz Geo Mono Red Grn Ble	Patch 1 202 85 15 47 20 53 32 65 tch Nur 1 778 287 76 112 93	2 807 341 59 186 78 211 127 260 mber 20 2 3114 1148 302 446 373	er 14 - 2.1 890 376 65 205 86 233 140 287 - Neut 2.1 3433 1266 333 492 411	Green 2.25 1021 431 75 236 99 267 161 329 ral (0.2 3941 1454 382 565 472	3 1816 766 133 419 176 475 285 586 3D) 3 7006 2584 680 1004 838	Px Sz Geo Mono Red Grn Ble Cyn Mgn Ylw Pa' Pa' Pa' Pa' Pa' Pa' Pa' Ble Geo Red Grn Ble	Patc 1 361 68 48 14 9 16 54 57 tch Num 1 477 177 46 69 58	Num           2           1446           270           191           55           35           64           217           230           nber 21           1909           706           185           274           230	ber 15 2.1 1594 298 210 61 39 71 239 253 - Neut 2.1 2104 779 204 302 254	- Red 2.25 1830 342 241 70 44 81 275 291 tral (0.4 2.25 2416 894 234 347 291	3 3253 608 429 124 79 144 488 517 4D) 3 4294 1589 416 617 518	Px Sz Geo Mono Red Grn Ble Cyn Mgn Ylw Pat Px Sz Geo Mono Red Grn Ble	Patch           1           719           221           93           96           27           89           112           192           cch Num           1           271           100           26           39           33	2 2875 883 372 384 108 354 450 769 nber 22 1082 401 105 155 131	r 16 - 2.1 3169 974 410 423 119 391 496 848 - Neut 2.1 1193 442 116 171 144	2.25 3638 1118 470 486 137 448 569 974 ral (0.7 2.25 1370 507 133 197 165	3 6468 1987 836 243 797 1012 1731 0D) 3 2435 902 236 350 294	Px Sz Geo Mono Red Cyn Mgn Ylw Pat Px Sz Geo Mono Red Grn Ble	Patch P           1           504           127           56           31           41           61           91           80           tch Nun           1           123           46           12           18           15	2 2016 508 224 126 162 245 366 319 mber 23 2 493 183 47 71 60	217 - W 2.1 2223 560 247 139 179 270 403 351 - Neut 2.1 544 202 52 78 67	2,25 2552 643 284 159 206 310 463 403 ral (1.0 2.25 624 232 60 90 76	3 4537 1144 505 283 365 551 823 717 55D 3 1109 413 106 160 136	Px Sz Geo Mono Red Grn Ble Cyn Mgn Ylw Px Sz Geo Mono Red Grn Ble	Patc 1 267 121 12 49 58 96 62 58 atch N 1 45 17 4 6 6	2 1067 485 48 196 230 384 250 231 umber 2 181 67 17 26 22	2.1 1177 535 53 216 254 424 276 254 24 - Bla 200 74 19 29 25	Cyan 2.25 1351 614 60 248 291 487 316 292 6ck (1.5 229 85 229 85 222 33 28	3           2401           1091           107           441           518           865           562           519           D)           3           407           151           39           58           50
Px Sz Geo Mono Red Grn Ble Cyn Mgn Ylw Pa Px Sz Geo Mono Red Grn Ble Cyn	Patcl 1 134 60 6 17 36 49 38 18 18 18 1181 434 115 169 140 258	Numb           2           537           240           25           68           144           196           152           73           mber 19           2           4726           1735           458           678           558           1034	2.1 592 265 27 75 159 217 168 80 9 - Whi 5210 1913 505 747 616 1140	- Blue 2.25 679 304 31 87 182 249 92 ite (0.0 2.25 5981 2196 580 858 707 1308	3 1207 540 55 154 324 442 342 164 5D) 3 10633 3903 1031 1525 1256 2326	Px Sz Geo Mono Red Grn Ble Cyn Ylw Pat Px Sz Geo Mono Red Grn Ble Cyn	Patch 1 202 85 15 47 20 53 32 65 tch Nur 1 778 287 76 112 93 171	2 807 341 59 186 78 211 127 260 mber 20 2 3114 1148 302 446 373 685	er 14 - 2.1 890 376 65 205 86 233 140 287 - Neut 2.1 3433 1266 333 492 411 756	Green 2.25 1021 431 75 236 99 267 161 329 ral (0.2 3941 1454 382 565 472 867	3 1816 766 133 419 176 475 285 586 <b>3D</b> <b>3</b> 7006 2584 680 1004 838 1542	Px Sz Geo Mono Red Grn Ble Cyn Ylw Pa Sz Geo Mono Red Grn Ble Cyn	Patc 1 361 68 48 14 9 16 54 57 tch Nun 1 477 177 46 69 58 106	Num           2           1446           270           191           55           35           64           217           230           mber 21           1909           706           185           274           230           422	ber 15 2.1 1594 298 210 61 39 71 239 253 - Neut 2.1 2104 779 204 302 254 466	- Red 2.25 1830 342 241 70 44 81 275 291 tral (0.4 894 2416 894 2416 894 2416 894 241 534	3 3253 608 429 124 79 144 488 517 4D) 3 4294 1589 416 617 518 950	Px Sz Geo Mono Red Grn Ble Cyn Ylw Pat Px Sz Geo Mono Red Grn Ble Cyn	Patch           1           719           221           93           96           27           89           112           192           cch Nun           1           271           100           26           39           33           60	2 2875 883 372 384 108 354 450 769 nber 22 1082 401 105 155 131 240	r 16 - 2.1 3169 974 410 423 119 391 496 848 - Neut 2.1 1193 442 116 171 144 264	2.25 3638 1118 470 486 137 448 569 974 ral (0.7 2.25 1370 507 133 197 165 303	3 6468 1987 836 243 797 1012 1731 0D) 3 2435 902 236 350 294 539	Px Sz Geo Mono Red Ble Cyn Mgn Ylw Pat Px Sz Geo Mono Red Grn Ble Cyn	1           504           127           56           31           41           61           91           80           tch Nun           123           46           12           18           15           28	2 2016 508 224 126 162 245 366 319 mber 23 2 493 183 47 71 60 110	217 - W 2.1 2223 560 247 139 179 270 403 351 - Neut 2.1 544 202 52 78 67 122	2.25 2552 643 284 159 206 310 463 403 ral (1.0 2.25 624 232 60 90 76 140	3 4537 1144 505 283 365 551 823 717 5D) 3 1109 413 106 160 136 248	Px Sz Geo Mono Red Grn Ble Cyn Ylw P X Sz Geo Mono Red Grn Ble Cyn	Patc 1 267 121 12 49 58 96 62 58 atch N 1 45 17 4 6 6 10	Number           1067           485           48           196           230           384           250           231           umber           181           67           17           26           22           41	2.1 1177 535 53 216 254 424 276 254 24 - Bla 200 74 19 29 25 45	- Cyan 2.25 1351 614 60 248 291 487 316 292 487 229 85 229 85 229 85 222 33 28 51	3           2401           1091           107           441           518           865           562           519           D)           3           407           151           39           58           50           92
Px Sz Geo Mono Red Grn Ble Cyn Ylw Pa Sz Geo Mono Red Grn Ble Cyn Mgn	Patci 1 134 60 6 17 36 49 38 18 18 18 1181 1181 115 169 140 258 234	Numb           2           537           240           25           68           144           196           152           73           mber 19           4726           1735           458           678           558           1034           938	2.1 592 265 27 75 159 217 168 80 9 - Whi 5210 1913 505 747 616 1140 1034	- Blue 2.25 679 304 31 87 182 249 192 92 ite (0.0 2.25 5981 2196 580 858 707 1308 1187	3 1207 540 55 154 324 442 342 164 5D) 3 10633 3903 1031 1525 1256 2326 2110	Px Sz Geo Mono Red Grn Ble Cyn Ylw Pat Px Sz Geo Mono Red Grn Ble Cyn Mgn	Patch 1 202 85 15 47 20 53 32 65 tch Nur 1 778 287 76 112 93 171 156	2 807 341 59 186 78 211 127 260 mber 20 2 3114 1148 302 446 373 685 623	er 14 - 2.1 890 376 65 205 86 233 140 287 - Neut 3433 1266 333 492 411 756 687	Green           2.25           1021           431           75           236           99           267           161           329           tral (0.2           2.25           3941           1454           382           565           472           867           789	3 1816 766 133 419 176 475 285 586 3D) 3 7006 2584 680 1004 838 1542 1402	Px Sz Geo Mono Red Grn Ble Cyn Ylw Pa Sz Geo Mono Red Grn Ble Cyn Ble Cyn Mgn	Patc 1 361 68 48 14 9 16 54 57 57 57 57 57 57 177 46 69 58 106 96	Num           2           1446           270           191           55           64           217           230           mber 21           1909           706           185           274           230           422           383	ber 15 2.1 1594 298 210 61 39 71 239 253 - Neut 2104 779 204 302 254 466 423	- Red 2.25 1830 342 241 70 44 81 275 291 tral (0.4 2.25 2416 894 2347 347 347 291 534 485	3 3253 608 429 124 79 144 488 517 <b>4</b> 0 <b>3</b> 4294 1589 416 617 518 950 863	Px Sz Geo Mono Red Grn Ble Cyn Mgn Pat Px Sz Geo Mono Red Grn Ble Cyn Red Grn Ble Cyn	Patch           1           719           221           93           96           27           89           112           192           ch Nun           1           271           100           26           39           33           60           54	2 2875 883 372 384 108 354 450 769 nber 22 1082 401 105 155 131 240 218	r 16	2.25 3638 1118 470 486 137 448 569 974 <b>2.25</b> 1370 507 133 197 165 303 276	3 6468 1987 836 863 243 797 1012 1731 0D) 3 2435 902 236 350 294 539 490	Px Sz Geo Mono Red Grn Ble Cyn Ylw Pat Px Sz Geo Mono Red Grn Ble Cyn Ble Cyn	1           504           127           56           31           41           61           91           80           tch Nun           123           46           12           18           15           28           25	2 2016 508 224 126 162 245 366 319 <b>nber 23</b> 493 183 47 71 60 110 100	2.1 2223 560 247 139 179 270 403 351 - Neut 2.1 544 202 52 78 67 122 110	2.25 2552 643 284 159 206 310 463 403 rel (1.0 2.25 624 232 60 90 76 140 126	3 4537 1144 505 283 365 551 823 717 550 3 1109 413 106 160 136 248 224	Px Sz Geo Mono Red Grn Ble Cyn Mgn Px Sz Geo Mono Red Grn Ble Cyn Mgn	Patc 1 267 121 12 49 58 96 62 58 atch N 1 45 17 4 6 6 10 9	Number           1067           485           48           196           230           384           250           231           umber           1           67           17           26           22           41           37	2.1 1177 535 53 216 254 424 276 254 24 - Bla 200 74 19 29 25 45 40	- Cyan 2.25 1351 614 60 248 291 487 316 292 	3           2401           1091           107           441           518           865           562           519           D)           3           407           151           39           50           92           82

## Table 3. Photoelectrons per lux-second for a f1.4 lens imaging diffusely lit MacBeth Color Checker patches with CIE D55 illumination at 5 lux for an exposure time of 10ms.

-	Patch	Numbe	er 1 - Da	ark Skin	£		Patch	Numbe	r 2 - Lig	ht Skin	2	-	Patch	Numbe	er 3 - Bl	ue Sky		-	Patch	Numb	er 4 - F	oliage		1	Patch N	lumber	5 - Blu	e Flowe	er	F	Patch N	umber	6 - Blui	sh Gree	in
Px Sz	1	2	2.1	2.25	3	Px Sz	1	2	2.1	2.25	3	Px Sz	1	2	2.1	2.25	3	Px Sz	1	2	2.1	2.25	3	Px Sz	1	2	2.1	2.25	3	Px Sz	1	2	2.1	2.25	3
Geo	8	33	36	42	74	Geo	28	111	122	140	249	Geo	13	53	58	67	118	Geo	7	29	32	37	66	Geo	22	87	96	111	197	Geo	24	97	107	122	218
Mono	2	9	10	11	20	Mono	8	34	37	43	76	Mono	6	22	25	28	50	Mono	3	10	11	13	23	Mono	7	30	33	38	67	Mono	10	40	44	51	91
Red	1	4	4	5	8	Red	3	13	14	16	29	Red	1	4	4	5	9	Red	1	3	3	3	6	Red	2	6	7	8	15	Red	2	7	7	8	15
Grn	1	3	3	4	7	Grn	3	12	13	15	27	Grn	2	8	9	10	19	Grn	1	5	5	6	11	Grn	3	10	11	13	23	Grn	5	18	20	23	41
Ble	0	2	2	2	4	Ble	2	8	9	11	19	Ble	2	10	10	12	21	Ble	1	2	3	3	5	Ble	3	12	14	16	28	Ble	4	14	16	18	32
Cyn	1	4	4	5	9	Cyn	4	17	18	21	37	Cyn	4	16	17	20	35	Cyn	1	6	6	7	13	Cyn	5	20	22	25	45	Cyn	7	28	30	35	62
Mgn	1	5	6	7	12	Mgn	5	20	22	25	45	Mgn	3	12	14	16	28	Mgn	1	5	5	6	10	Mgn	4	17	19	22	39	Mgn	5	19	21	24	43
Ylw	2	7	7	8	15	Ylw	6	24	27	31	55	Ylw	3	11	13	14	26	Ylw	2	8	8	10	17	Ylw	4	15	17	20	35	Ylw	6	25	27	31	56
	Patch	Numb	er 7 - 0	Orange		P	atch N	umber	8 - Purp	lish Blu	e	Patch	Numbe	r 9 - Me	oderate	Red			Patch	Numb	er 10 -	Purple		Pa	tch Nu	mber 1	1 - Yell	ow Gre	en	Pa	tch Nu	mber 1	2 - Ora	nge Yell	ow
Px Sz	1	2	2.1	2.25	3	Px Sz	1	2	2.1	2.25	3	Px Sz	1	2	2.1	2.25	3	Px Sz	1	2	2.1	2.25	3	Px Sz	1	2	2.1	2.25	3	Px Sz	1	2	2.1	2.25	3
Geo	23	90	99	114	203	Geo	11	44	48	56	99	Geo	21	82	91	104	185	Geo	8	33	36	41	73	Geo	22	88	97	111	197	Geo	28	114	126	144	256
Mono	6	24	26	30	54	Mono	5	18	20	23	41	Mono	5	21	23	26	47	Mono	2	9	10	11	20	Mono	8	31	34	40	70	Mono	8	33	36	42	74
Red	3	13	15	17	30	Red	1	3	3	3	6	Red	3	12	13	15	27	Red	1	2	3	3	6	Red	2	9	10	11	20	Red	4	16	17	20	35
Grn	2	8	9	10	18	Grn	1	6	6	7	13	Grn	1	5	6	7	12	Grn	1	3	3	3	6	Grn	4	16	17	20	35	Grn	3	13	14	16	29
Ble	1	2	3	3	5	Ble	2	9	10	12	21	Ble	1	4	5	5	9	Ble	1	4	4	5	9	Ble	1	5	6	7	12	Ble	1	4	4	5	8
Cyn	2	7	7	9	15	Cyn	3	14	15	17	31	Cyn	2	7	8	9	16	Cyn	1	6	6	7	13	Cyn	4	16	18	20	36	Cyn	3	11	13	14	26
Mgn	4	15	16	19	33	Mgn	3	11	12	14	25	Mgn	4	15	17	19	34	Mgn	1	6	7	8	13	Mgn	3	13	15	17	30	Mgn	5	18	20	23	41
Ylw	5	21	23	26	47	Ylw	2	7	8	9	16	Ylw	4	16	17	20	36	Ylw	1	5	5	6	10	Ylw	6	26	28	33	58	Ylw	7	29	32	36	64
	_									_			1.6.7															-				_			
	Patc	h Num	ber 13	- Blue			Patch	Numb	er 14 -	Green			Patc	h Num	ber 15	Red		_	Patch	Numbe	er 16 - '	Yellow			Patch I	Numbe	r 17 - N	lagenta	1		Patc	h Numt	oer 18 -	Cyan	
Px Sz	Patc 1	h Numi 2	ber 13	- Blue 2.25	3	Px Sz	Patch 1	Numb	er 14 - 2.1	Green 2.25	3	Px Sz	Patc 1	h Num 2	2.1	Red 2.25	3	Px Sz	Patch 1	Numbe 2	er 16 - 1	Yellow 2.25	3	Px Sz	Patch I	Number 2	r 17 - N 2.1	lagenta 2.25	3	Px Sz	Patc 1	n Numt 2	2.1	Cyan 2.25	3
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Px Sz Geo Mono	Patc 1 7 3	2 27 12	2.1 30 13	- Blue 2.25 34 15	3 60 27	Px Sz Geo Mono	Patch 1 10 4	Numb 2 40 17	er 14 - 2.1 44 19	Green 2.25 51 22	3 91 38	Px Sz Geo Mono	Patc 1 18 3	h Num 2 72 14	2.1 80 15	Red 2.25 91 17	3 163 30	Px Sz Geo Mono	Patch 1 36 11	Numbe 2 144 44	er 16 - 1 2.1 158 49	Yellow 2.25 182 56	<b>3</b> 323 99	Px Sz Geo Mono	Patch 1 25 6	2 101 25	<b>2.1</b> 111 28	2.25 128 32	3 227 57	Px Sz Geo Mono	Patc 1 13 6	2 53 24	2.1 59 27	Cyan 2.25 68 31	3 120 55
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