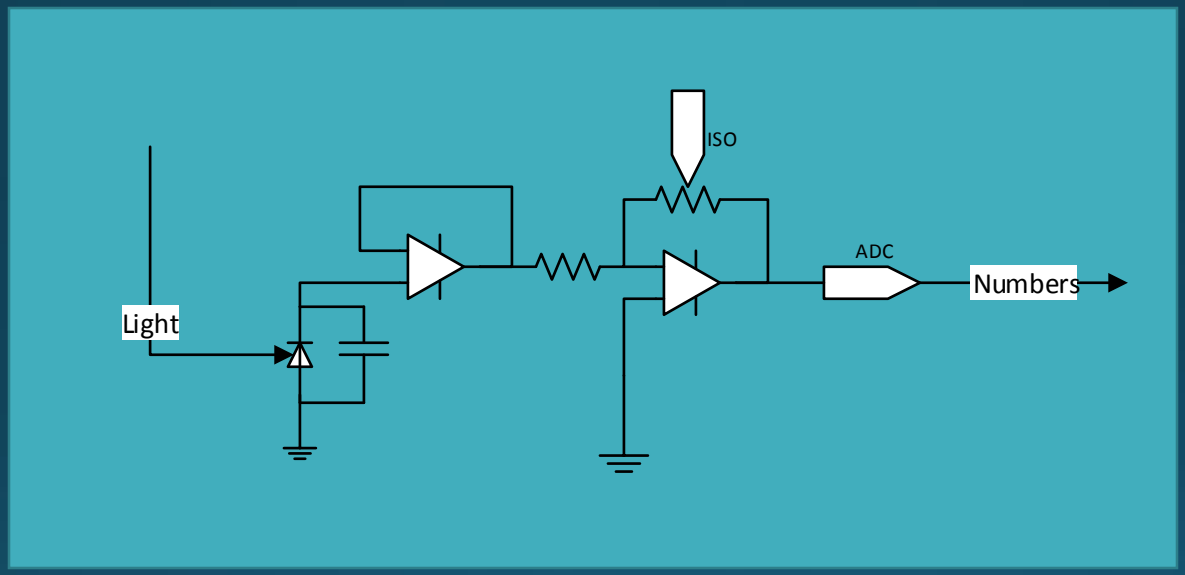
# Converting light to numbers

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# Raw conversion

- Demosaicing
- Conversion to a standard (usually RGB) color space
  - Color space primaries, white point
  - Nonlinearity
- Anti-alias compensation
- Noise reduction
- Sharpening
- Lens correction
- (Image editing)

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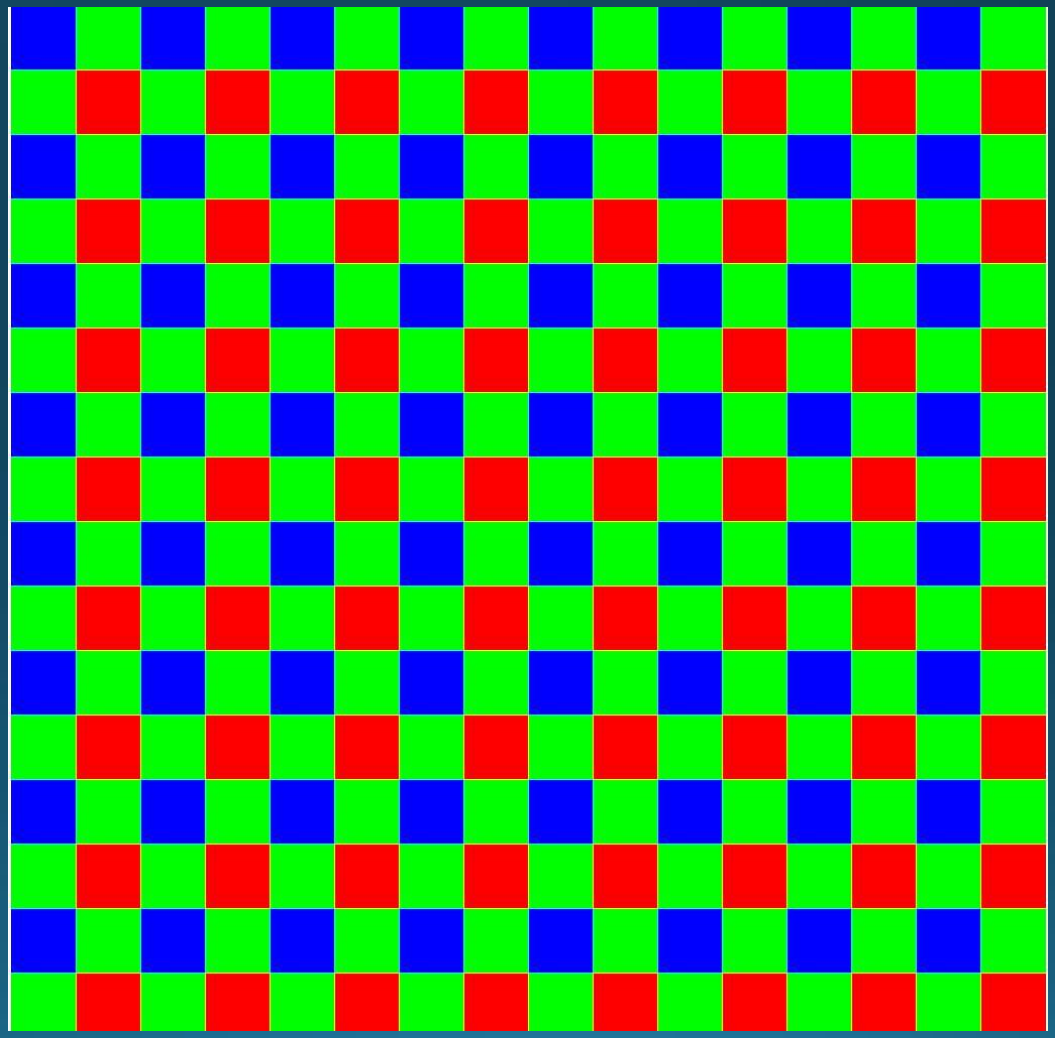
# The Bayer pattern



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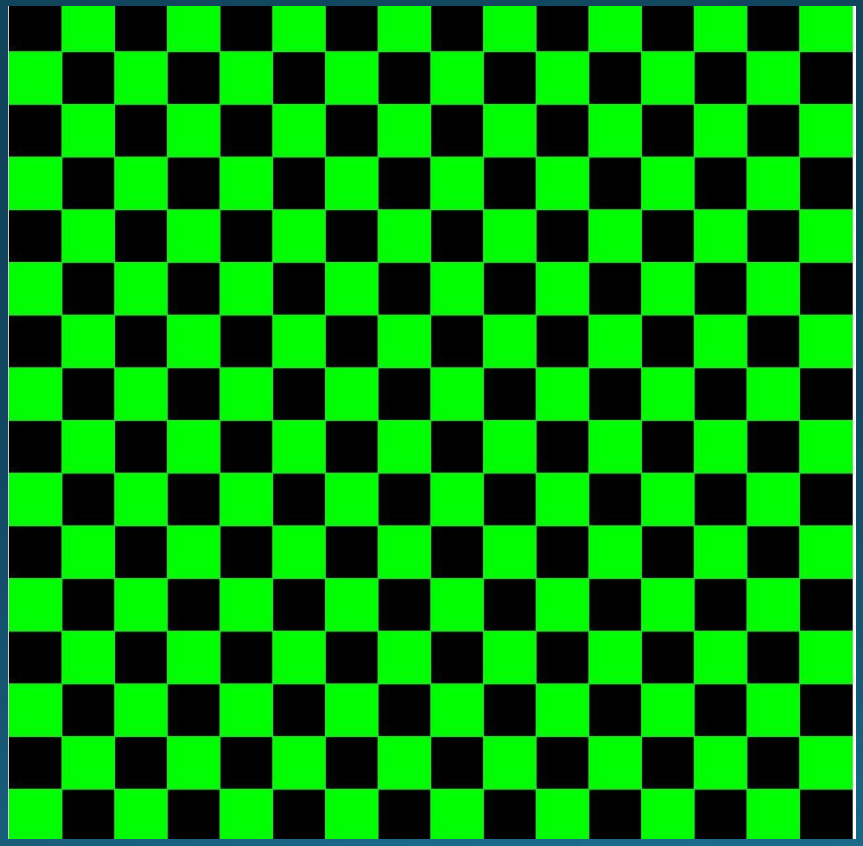

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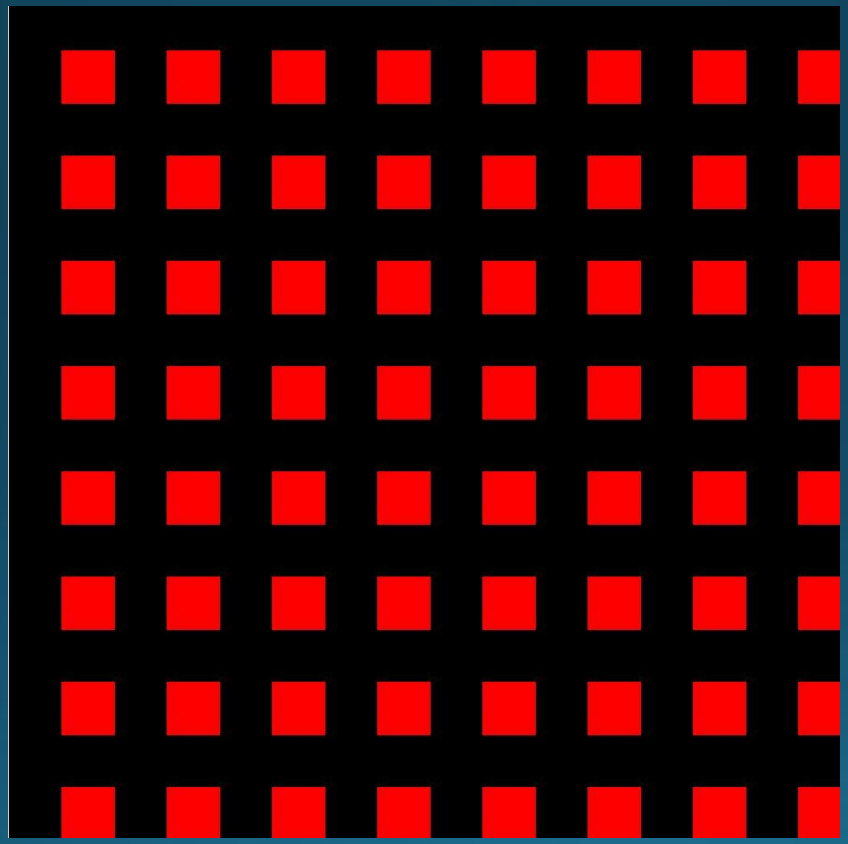
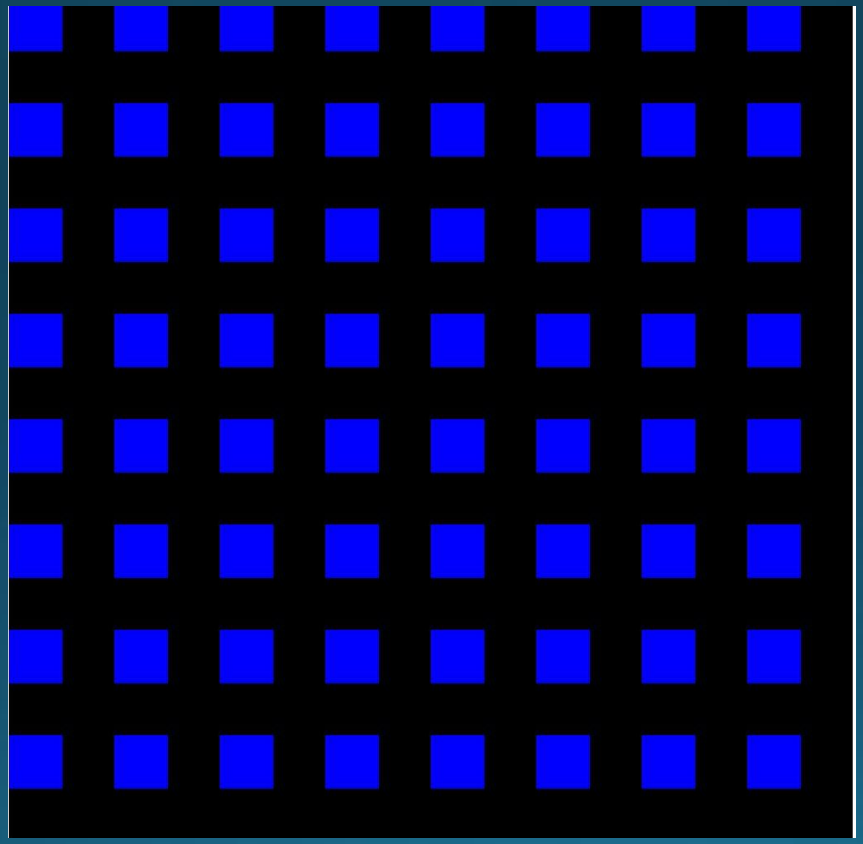


©2013 Jim Kasson



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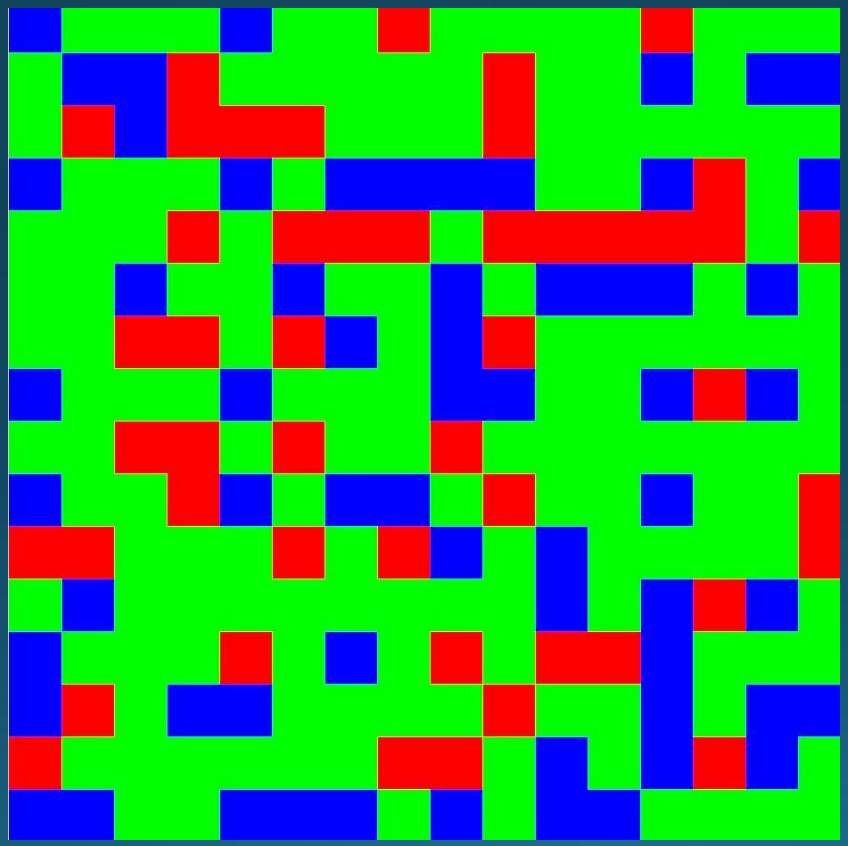
# The Kasson pattern



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# Missing data

- Half the pixels have no green data
- Three-quarters have no blue data
- Three-quarters have no red data
- Demosaicing is making up the missing data

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# Bilinear interpolation

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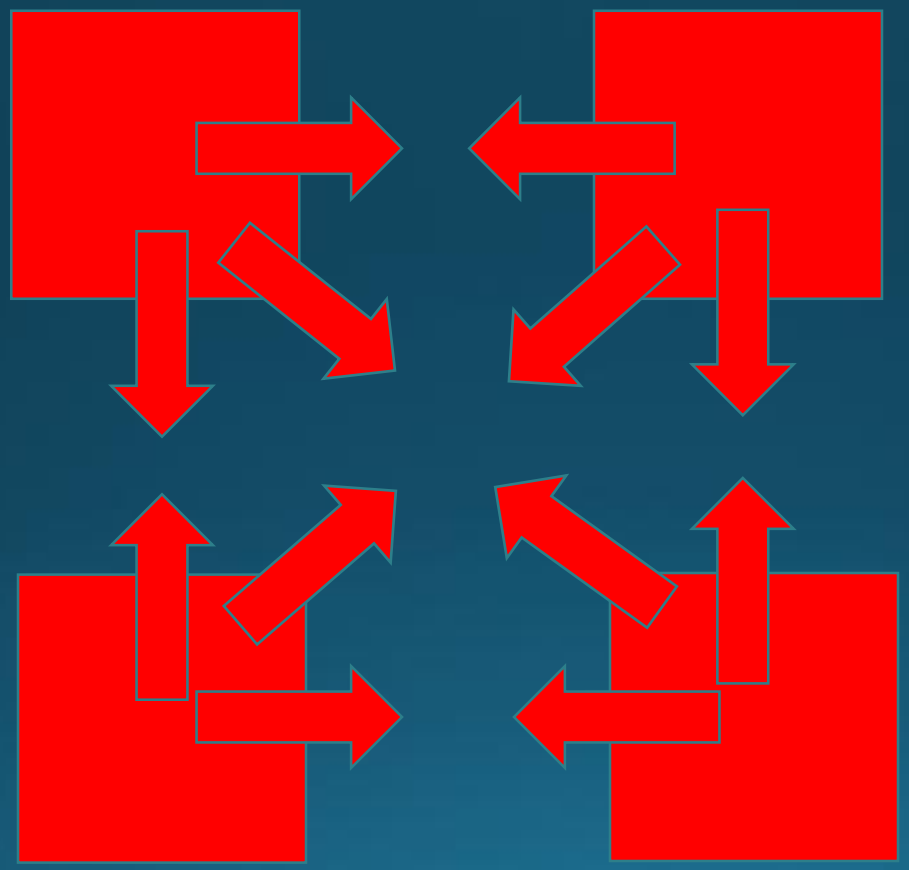
# Bilinear interpolation



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# Other interpolation methods

- Bicubic
- Variable Number of Gradients
- Patterned Pixel Grouping
- Adaptive Homogeneity-Directed
- Frequency-domain methods

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# Artifacts

- Different color photosites see different parts of the image
- High spatial frequencies appear at lower frequencies

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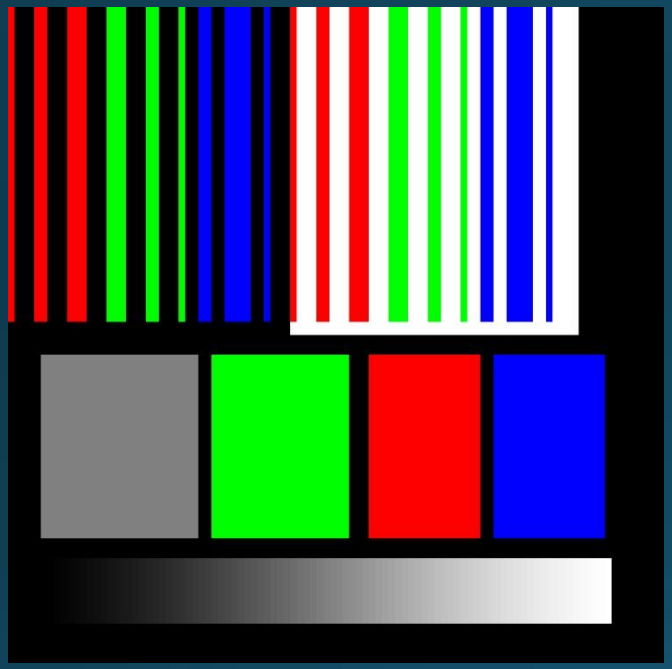
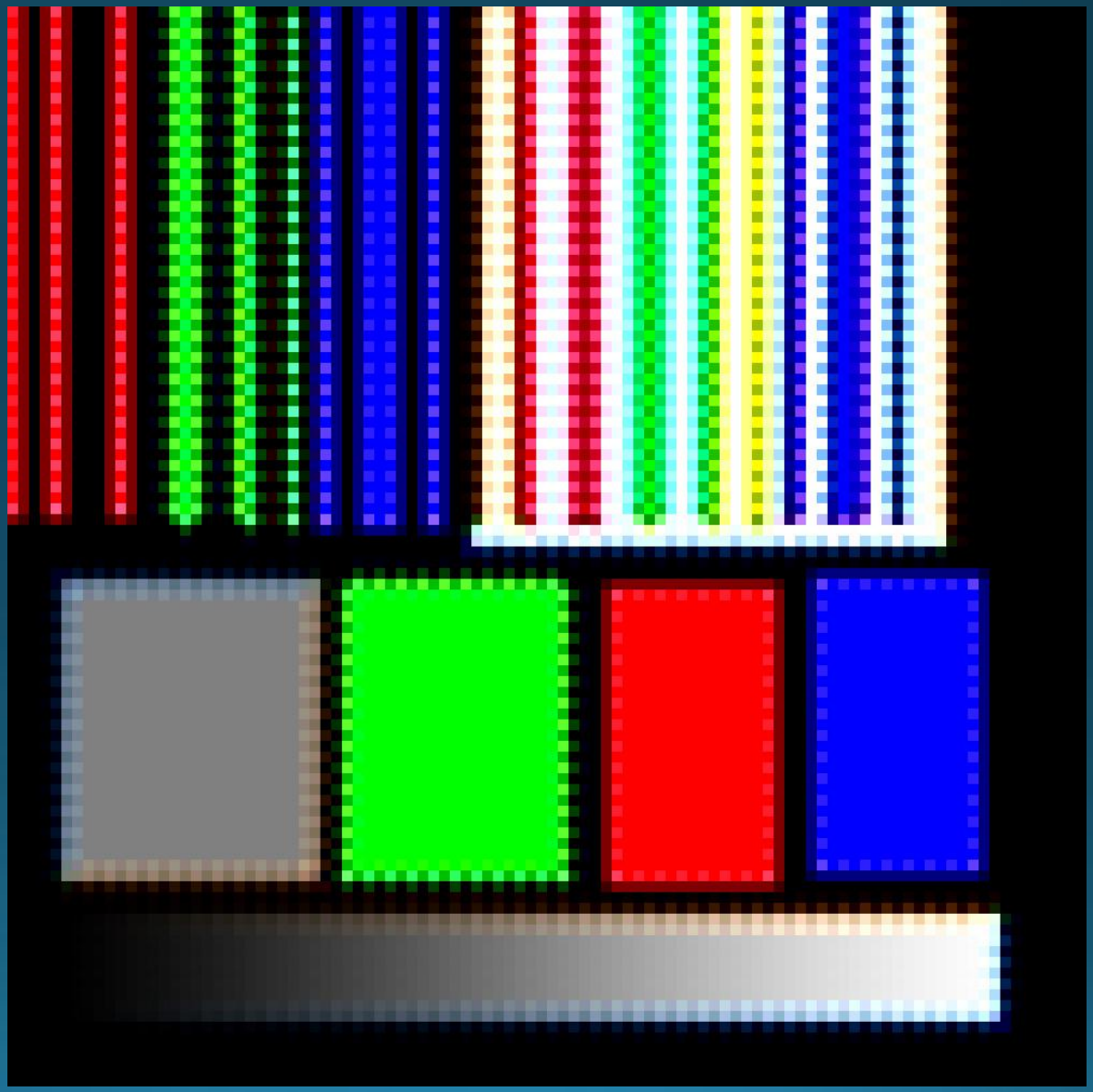
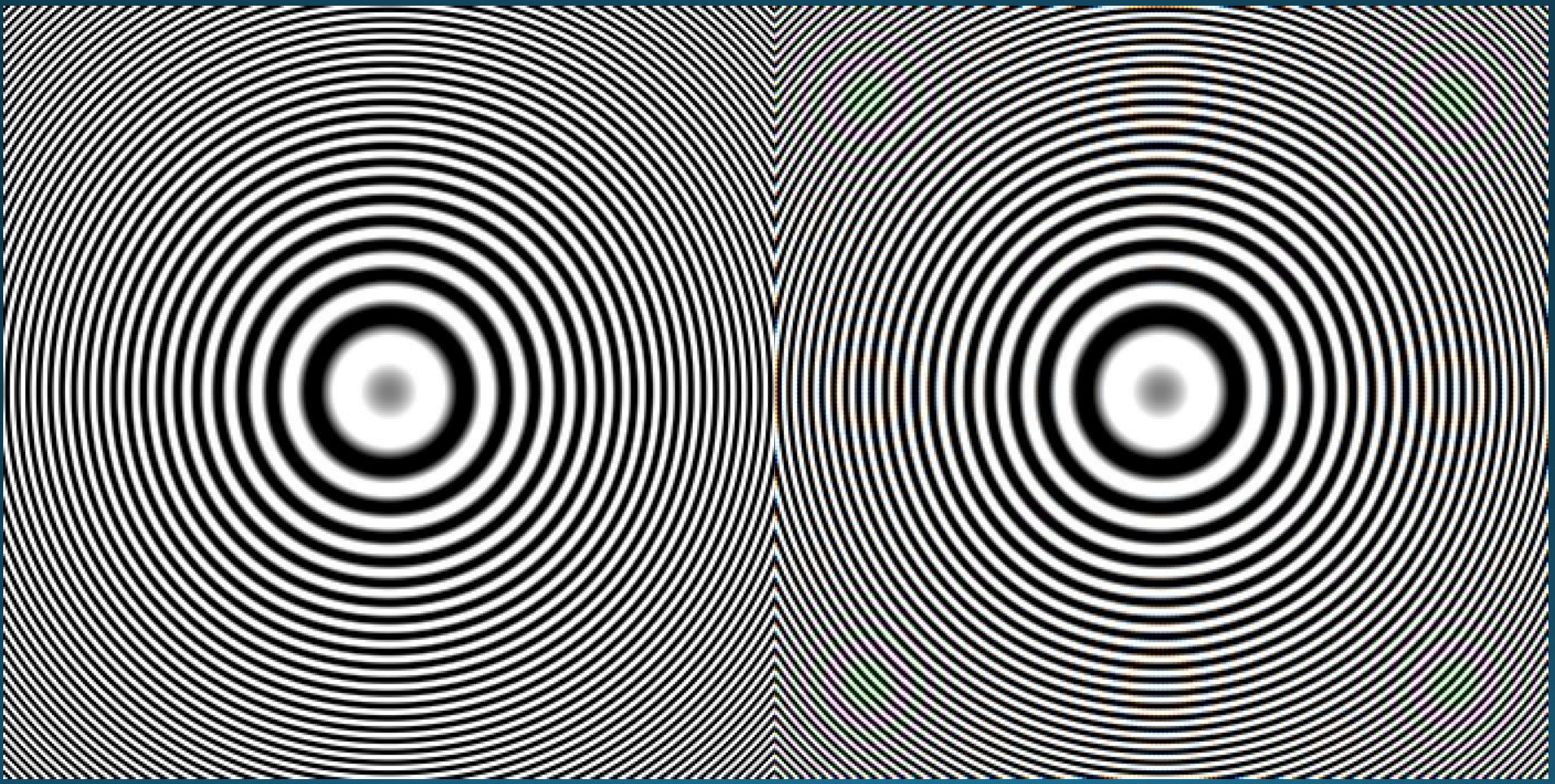
# Bayer interpolation artifacts





# Bayer sampling & demosacing artifacts



©2013 Jim Kasson

# Original scene

©2013 Jim Kasson

# Demosaiced with gradient-corrected bilinear interpolation

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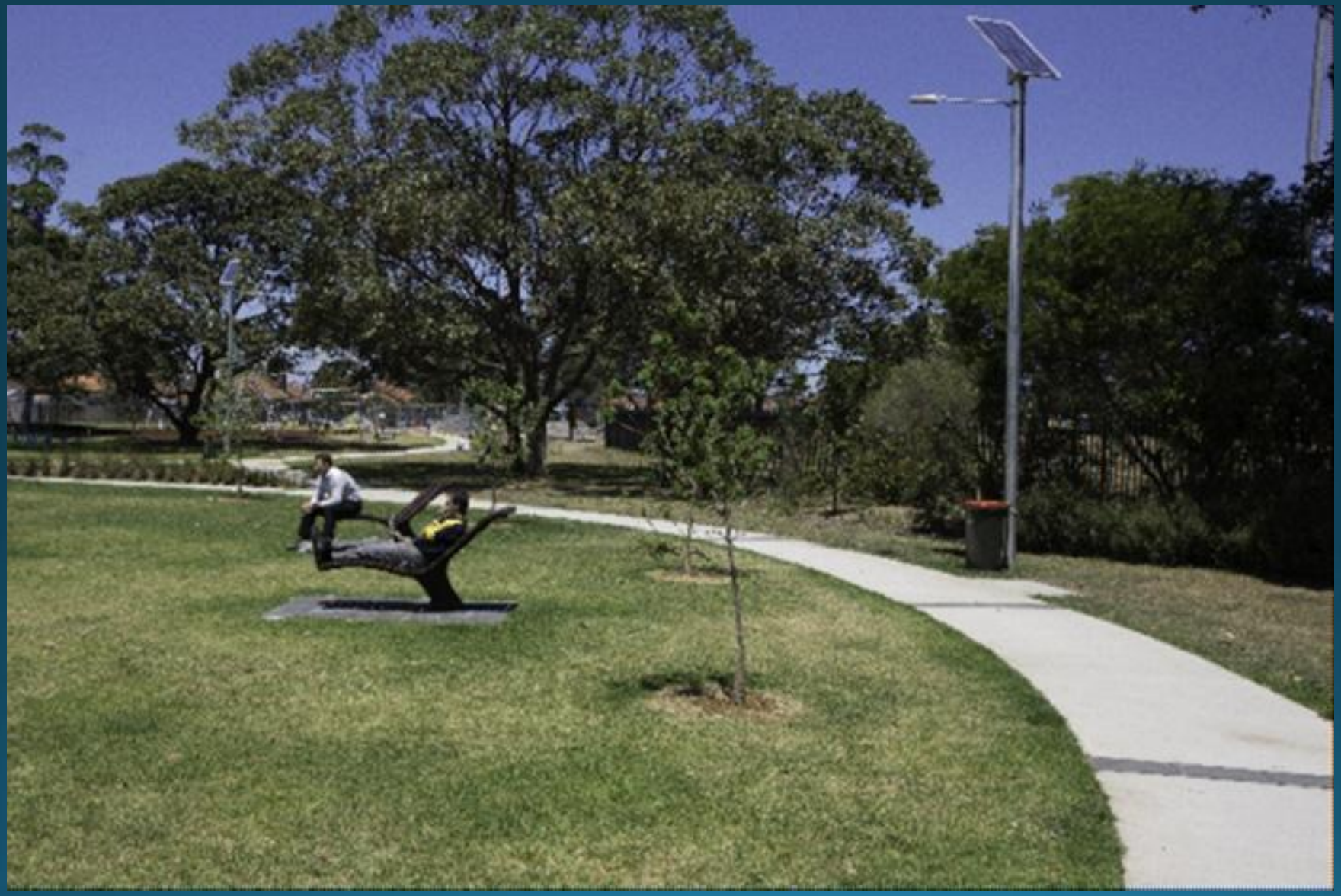
Anti-aliased with a 2x2 averaging filter, then demosaiced with gradient-corrected bilinear interpolation



©2013 Jim Kasson

# Original scene

©2013 Jim Kasson

# Luther-Ives condition

- It is possible to exactly convert a linear RGB representation of an image to standard colorimetric color space like sRGB, Adobe (1998) RGB, or ProPhoto RGB if and only if the spectral sensitivities of the three camera primaries are a three-by-three matrix multiplication away from CIE 1931 XYZ

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# Getting to standard primaries

$$\begin{bmatrix} R \\ G \\ B \end{bmatrix} = \begin{bmatrix} R_R & G_R & B_R \\ R_G & G_G & B_G \\ R_B & B_B & B_B \end{bmatrix} \times \begin{bmatrix} Rc \\ Gc \\ Bc \end{bmatrix}$$

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# White balance

- $$\begin{bmatrix} R \\ G \\ B \end{bmatrix} = \begin{bmatrix} C_R & 0 & 0 \\ 0 & 1 & 0 \\ 0 & 0 & C_B \end{bmatrix} \times \begin{bmatrix} R \\ G \\ B \end{bmatrix}$$
- Where do the coefficients come from?
  - WB settings in camera
    - Auto WB
    - Preset Lighting conditions
    - Custom WB
  - WB from raw developer
    - Presets
    - User color temp, offset
  - The choice is yours

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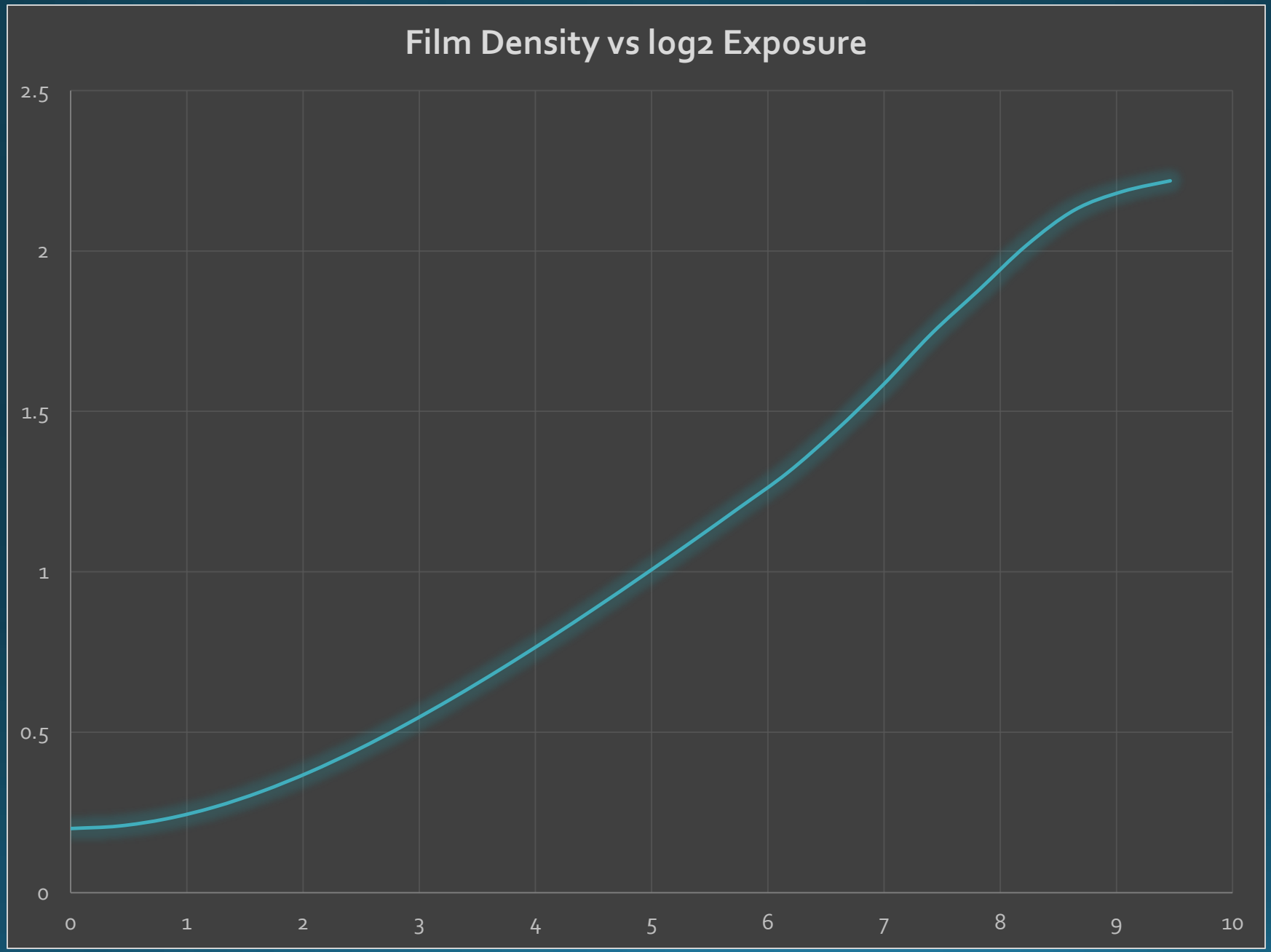
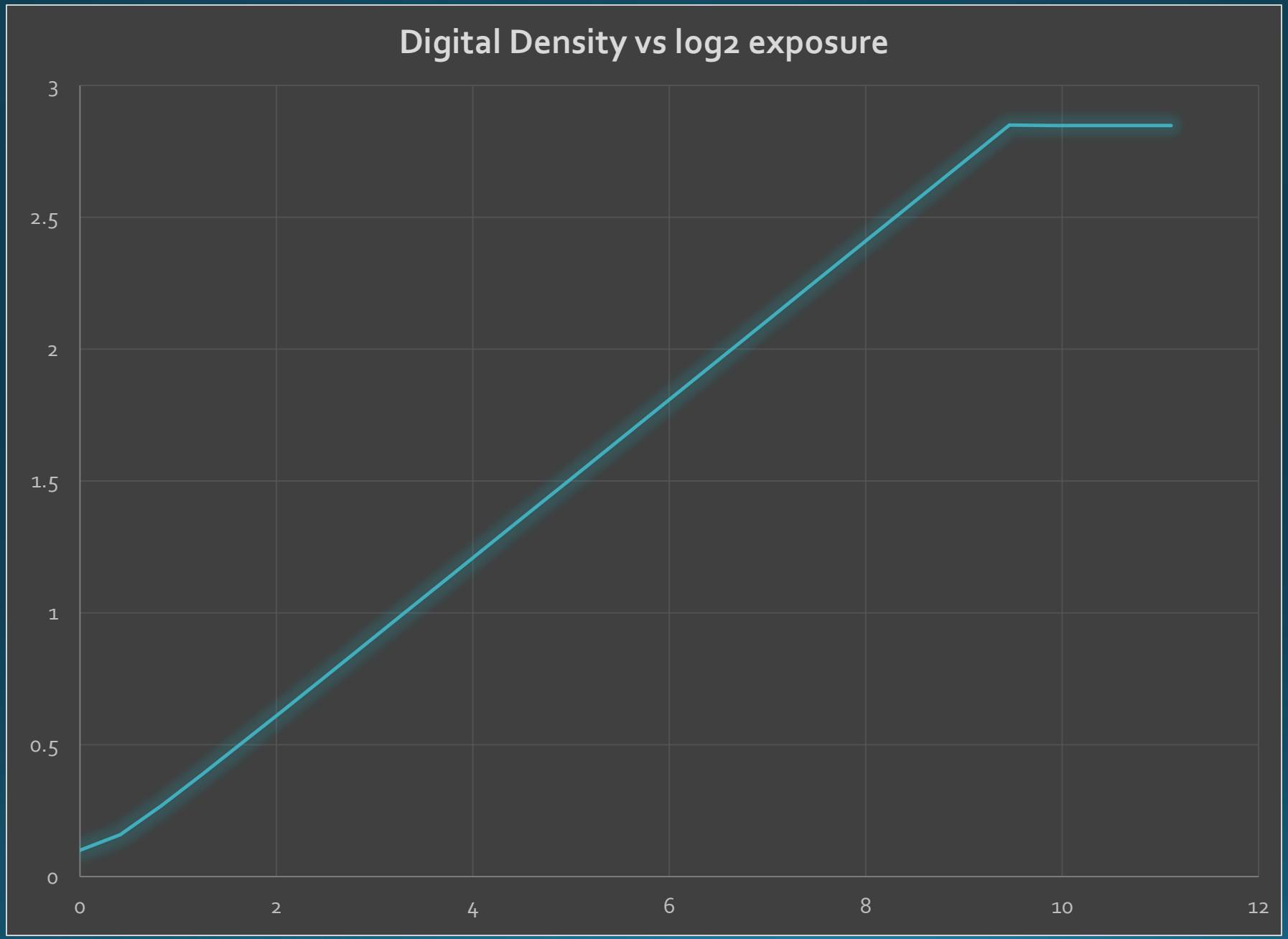



©2013 Jim Kasson

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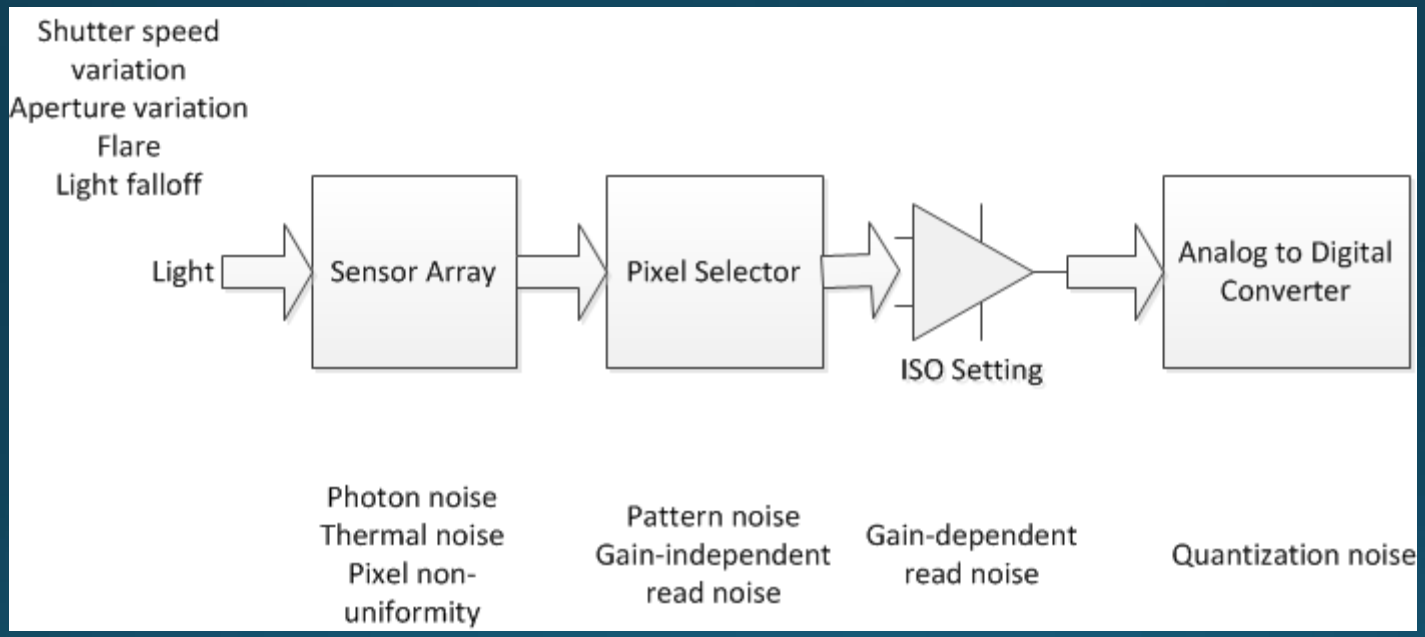
# Noise

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# Photon noise (aka shot noise, Poisson noise)

- Variance proportional to count
- Standard deviation proportional to square root of count
- $SNR \propto \sqrt{count}$
- SNR halves with a two-stop underexposure

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# Adding up Gaussian noise

- $N = \sqrt{\sum_1^n {n_i}^2}$
- Two equal noise sources produce a result that's 1.4 times either
- Two noise sources a factor of ten apart product a result that's 0.5% more than the larger one

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# When to worry about noise

- Thermal noise, dark current pixel nonuniformity: slow shutter speeds
- Normal PRNU: in theory, in the highlights; in practice, never
- Pattern noise: smooth gradients, heavy underexposure
- Read noise: heavy underexposure
- Photon noise: most of the time, and in the shadows

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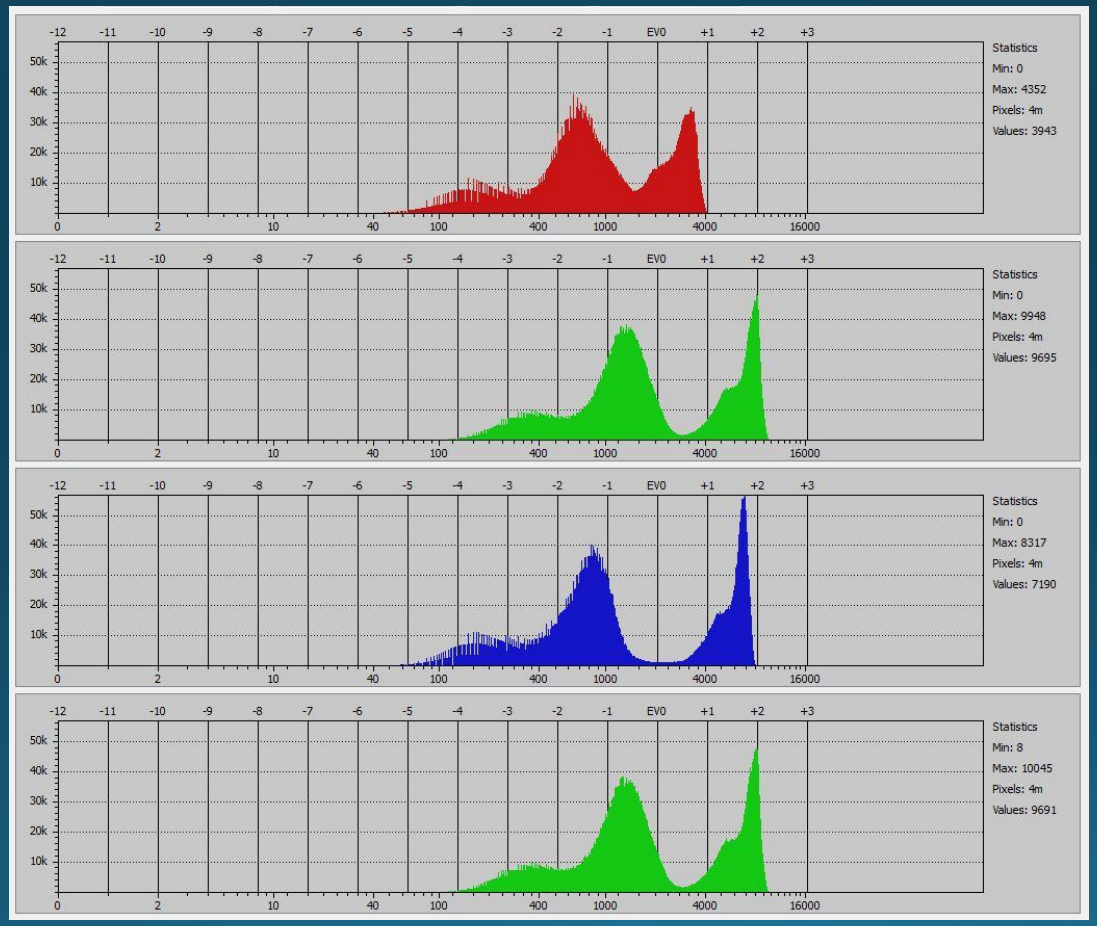
# A raw histogram

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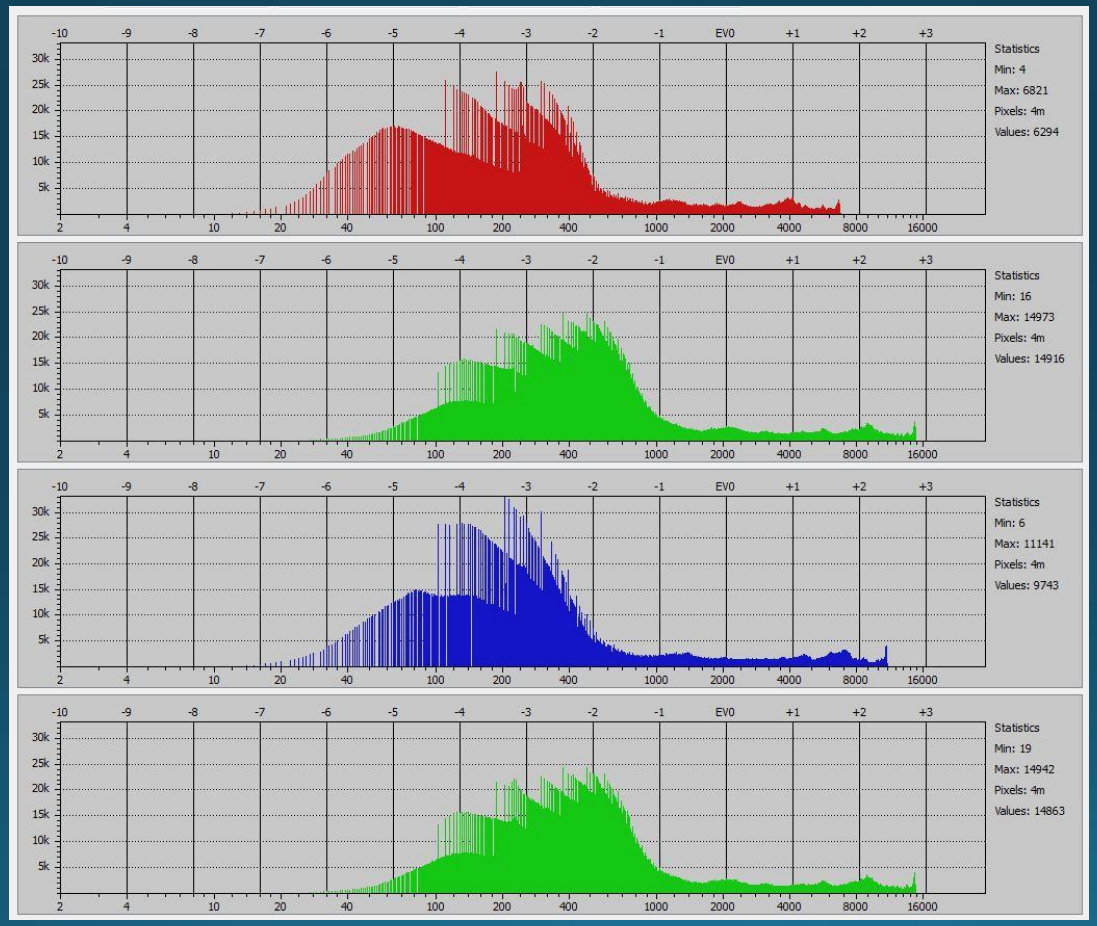
# A good raw histogram

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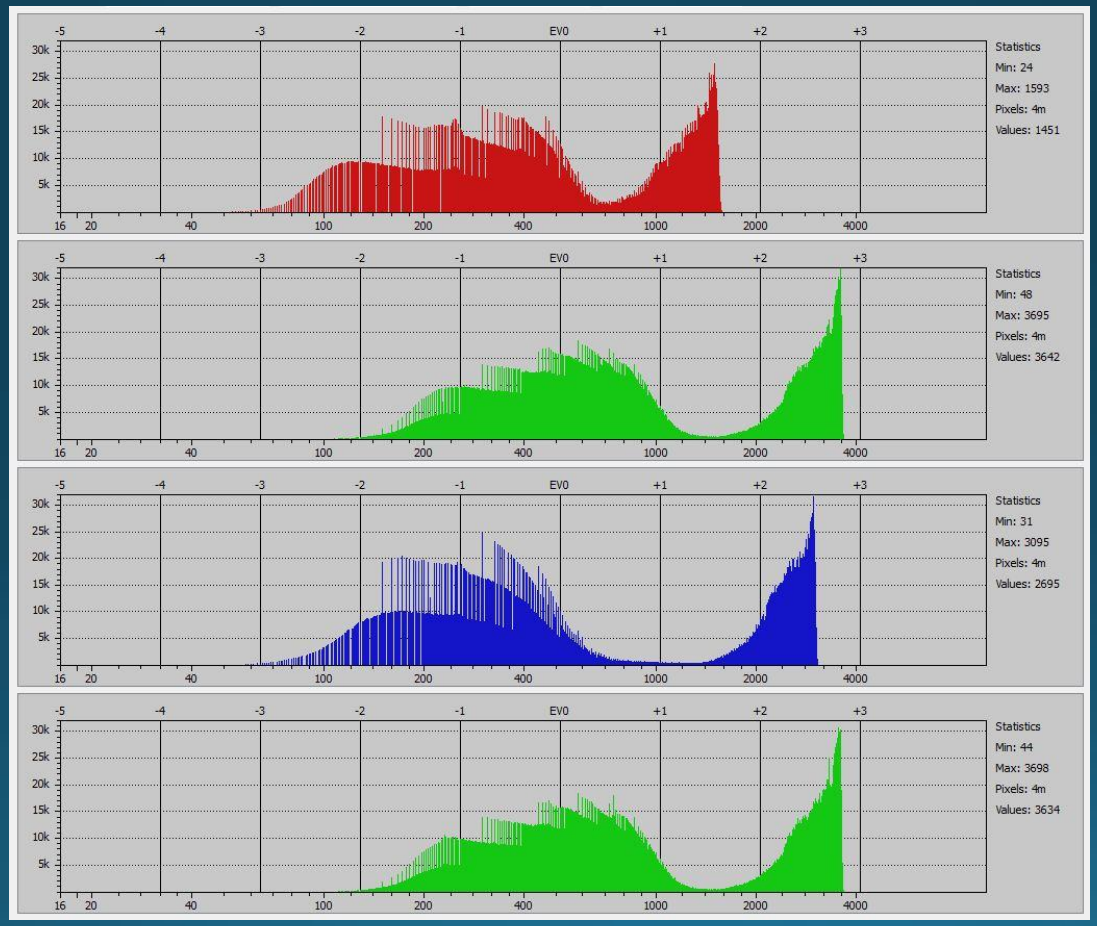
# A bad raw histogram

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# ETTR for more and smoother tones

- With a 14-bit converter
  - 8000+ levels in the top f-stop of the tone curve
  - 4000+ levels the next f-stop down
  - 2000+ levels the next f-stop down
  - 1000+ levels the next f-stop down
  - 500+ levels the next f-stop down
  - 255 levels the next f-stop down
  - 127 levels the next f-stop down

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# ETTR for less noise

- Shot noise is proportional to the square root of the pixel area
- Thus, it's proportional to the inverse of the pixel pitch.
  - Nikon D3s = 8.5 microns
  - Nikon D4 = 6.8 microns
  - Nikon D800 = 4.88 microns
  - Sony NEX-7 = 3.9 microns
  - IPhone 4s = 1.4 microns

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# Removing resolution from the noise equation

- SNR is proportional to the inverse of the square root of the sensor area
- Thus, it's proportional to the inverse of any linear dimension of the sensor area.

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# Diagonal dimensions

- Hasselblad H5D: 67 mm
- Full frame 35: 43 mm
- APS-C: 29 mm
- Four-thirds, micro four-thirds: 22 mm
- Leica D-Lux 6: 9.4 mm
- iPhone 5: 5.3 mm

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# All have the about the same resolution-adjusted SNR

- Nikon D4 with ETTR
- Sony NEX-6 a stop underexposed
- Micro four-thirds camera 2 stops under
- Leica D-Lux 6 4 stops under
- iPhone 5 6 stops under

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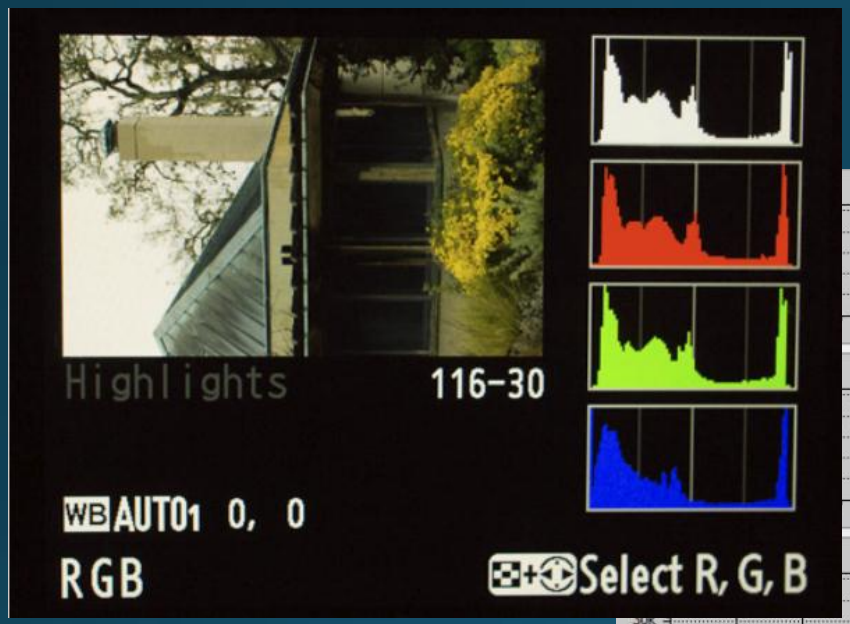
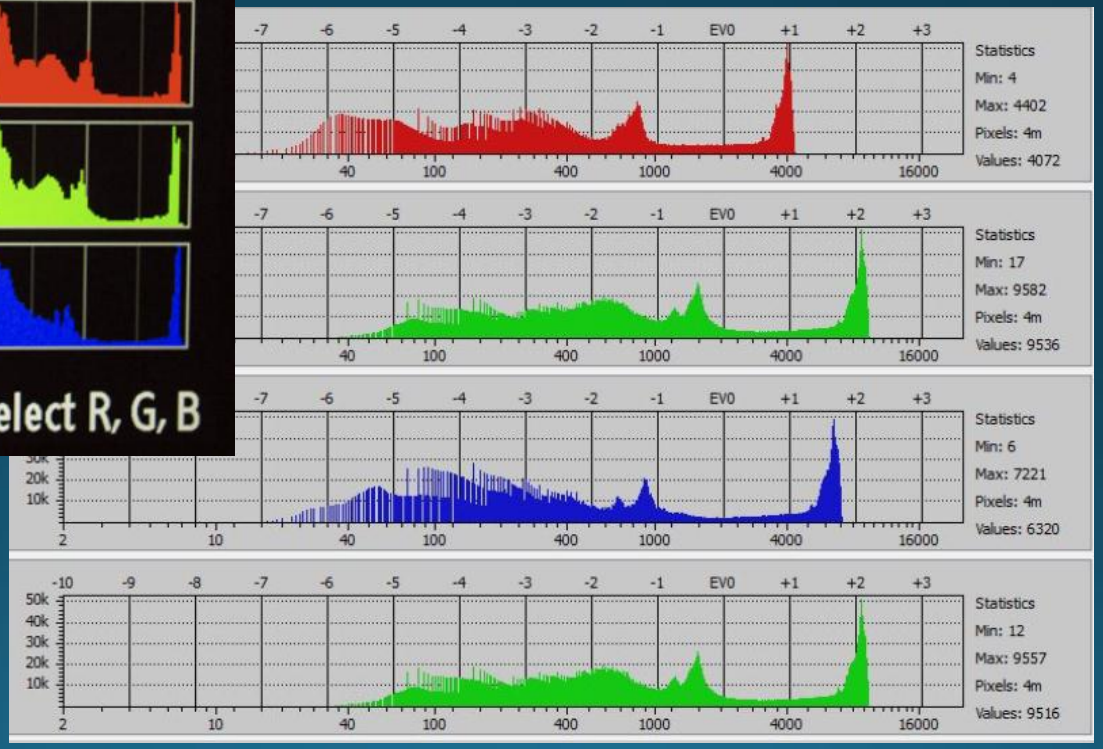
# In-camera histogram ~= raw histogram

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# Quick and dirty in-camera histogram correction

- Color space to Adobe RGB
- Set the white balance to about 3800 K and the color bias as green as it will go
- Reduce the contrast one or two steps

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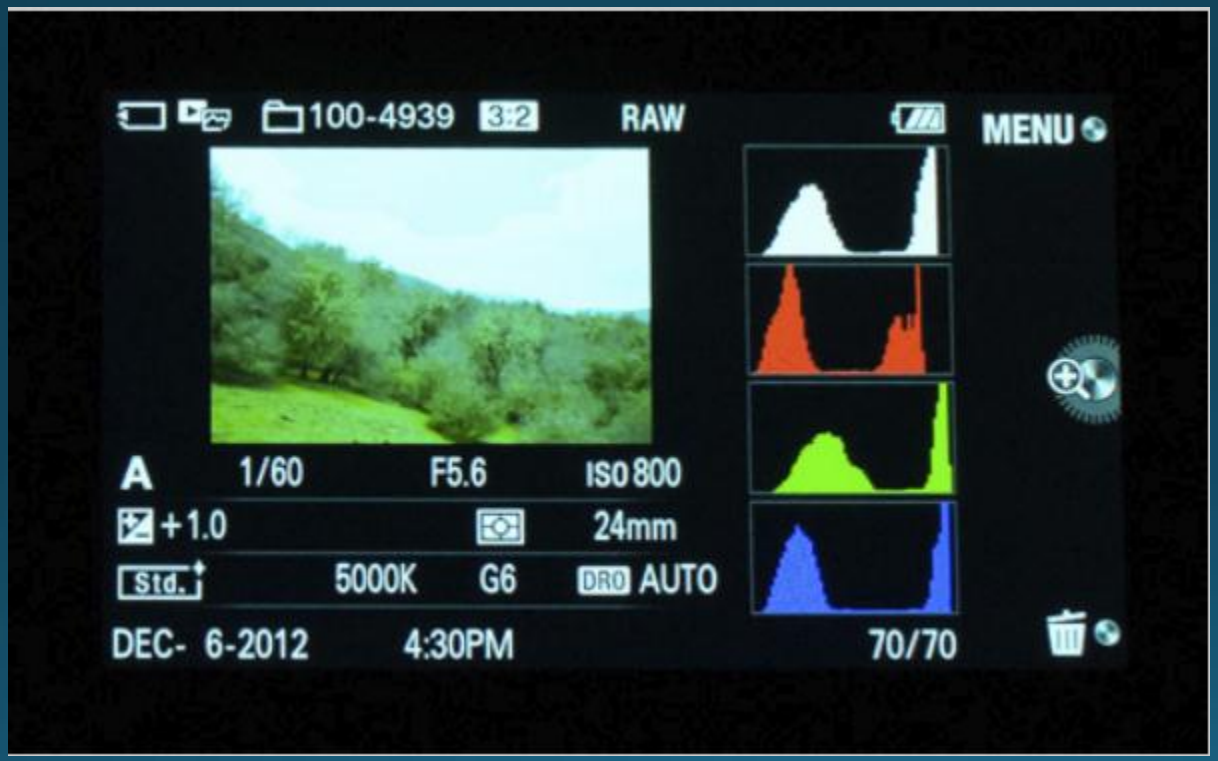
# Now your preview image looks funny

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# In-camera histogram correction by custom white balance

- In any RGB color space within the gamut of your monitor for which you know the gamma, make three exposures: one at 255/0/0, one at 0/255/0, one at 0/0/255.
- Bring the images into Rawdigger. Enter the average values of the red, green, and blue raw pixels into the appropriate columns in a spreadsheet you can find here: http://blog.kasson.com/?page_id=2481.
- Enter the color space gamma into the spreadsheet.
- Enter the desired raw value for the target, usually two or three stops below clipping.
- Read the target RGB values from the output cells, and fill the test target with that color in Photoshop.
- Balance the camera's WB to the test target.

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# So, just turn up the ISO, right?

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# No so fast…

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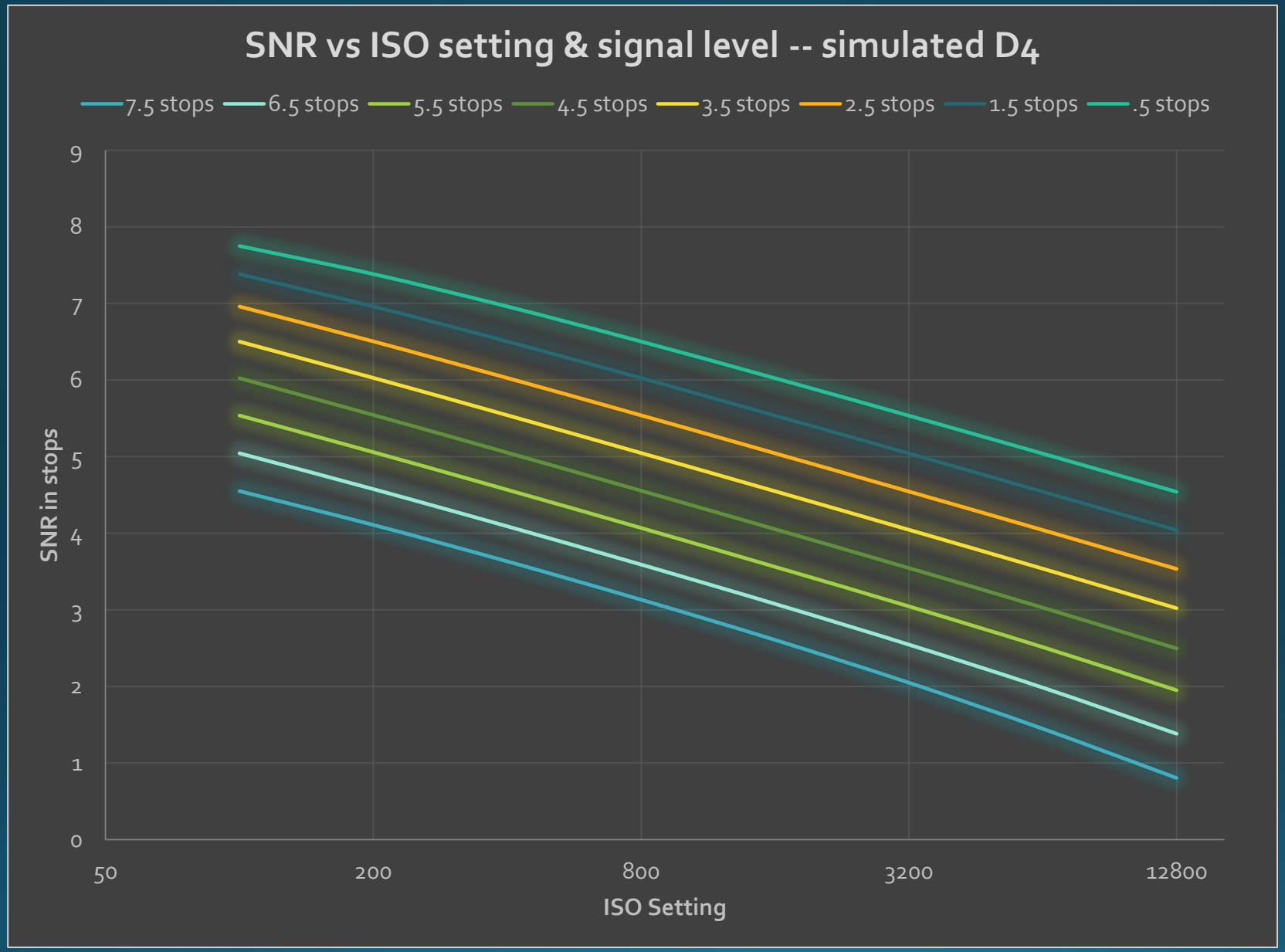


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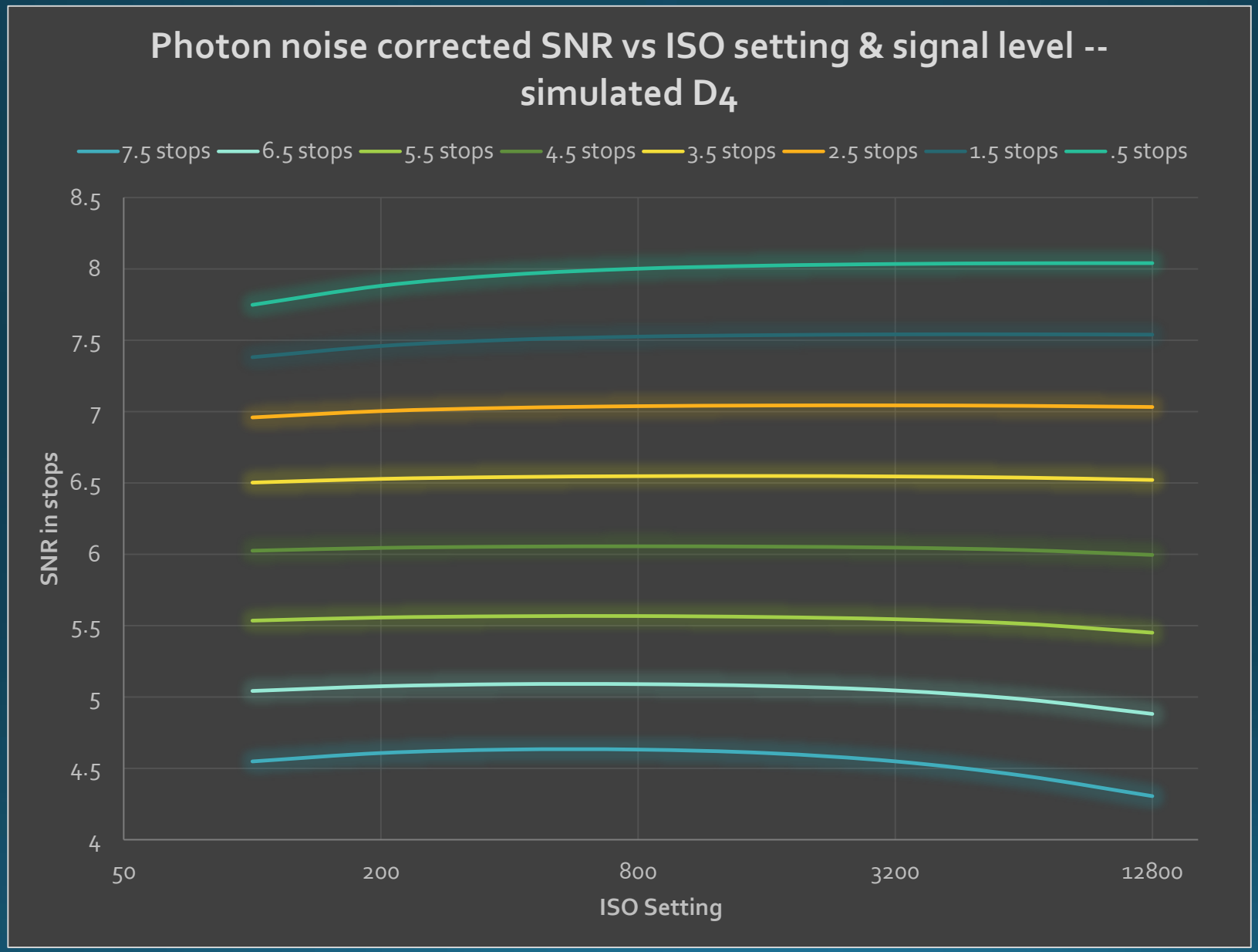


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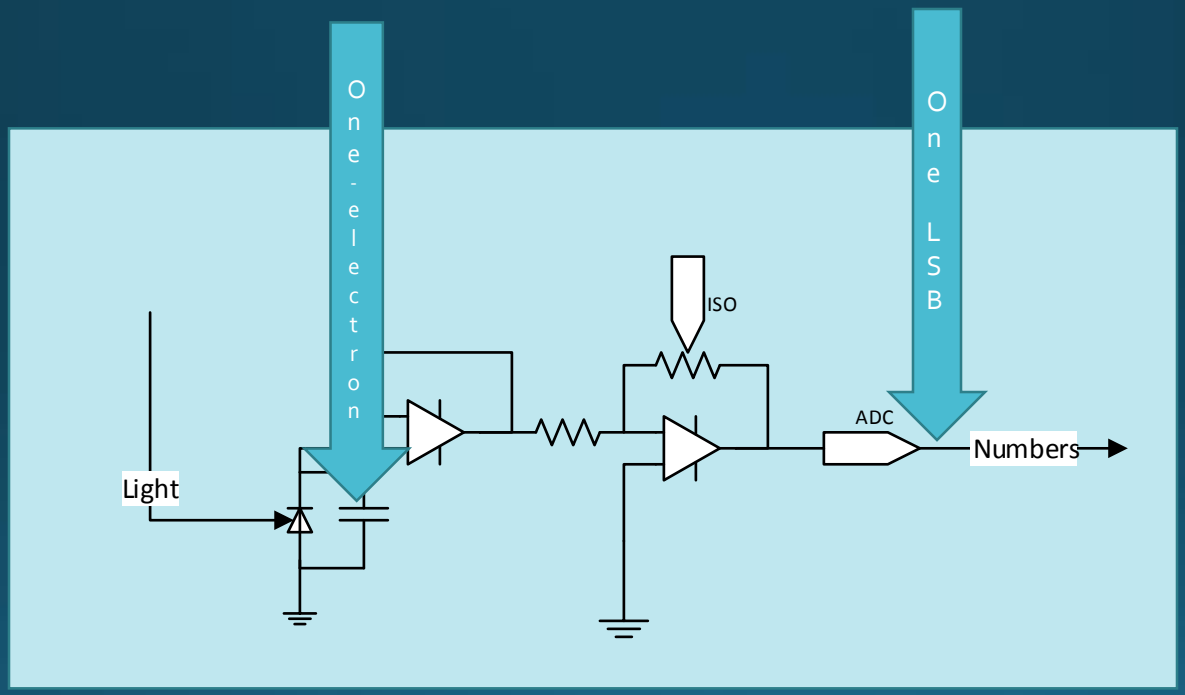
# Unity gain ISO

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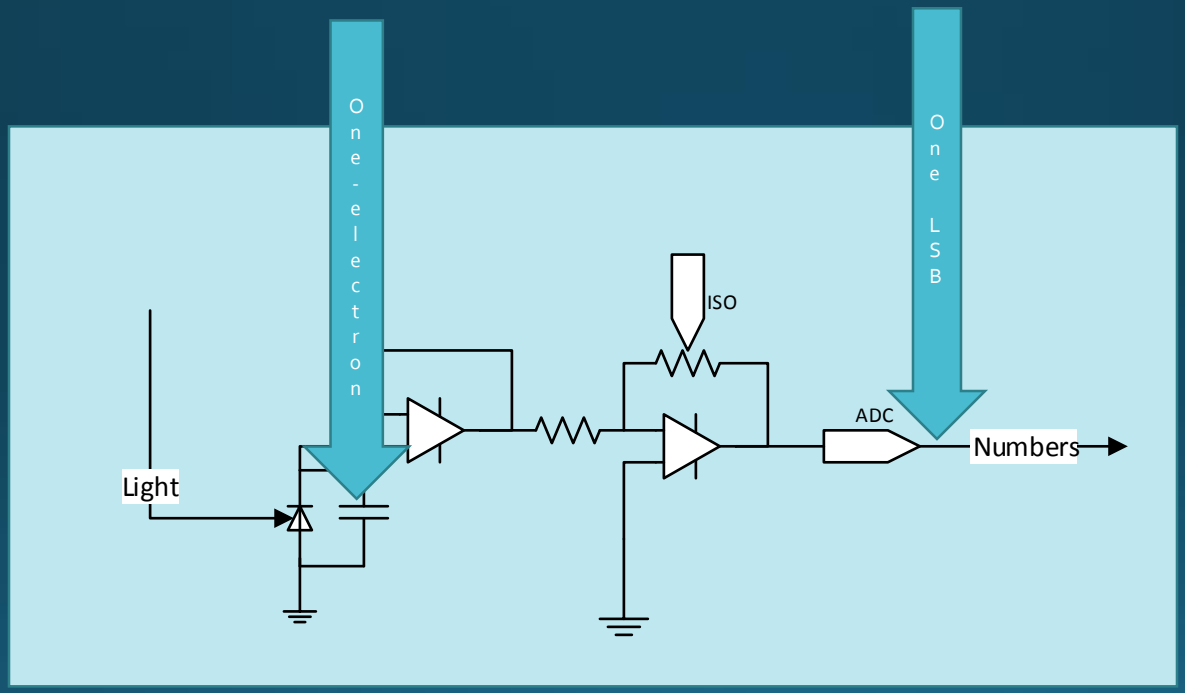
# Finding unity gain ISO

$$ISOunity\ gain = \frac{ISOtest \times Sadc}{Nadc^2}$$

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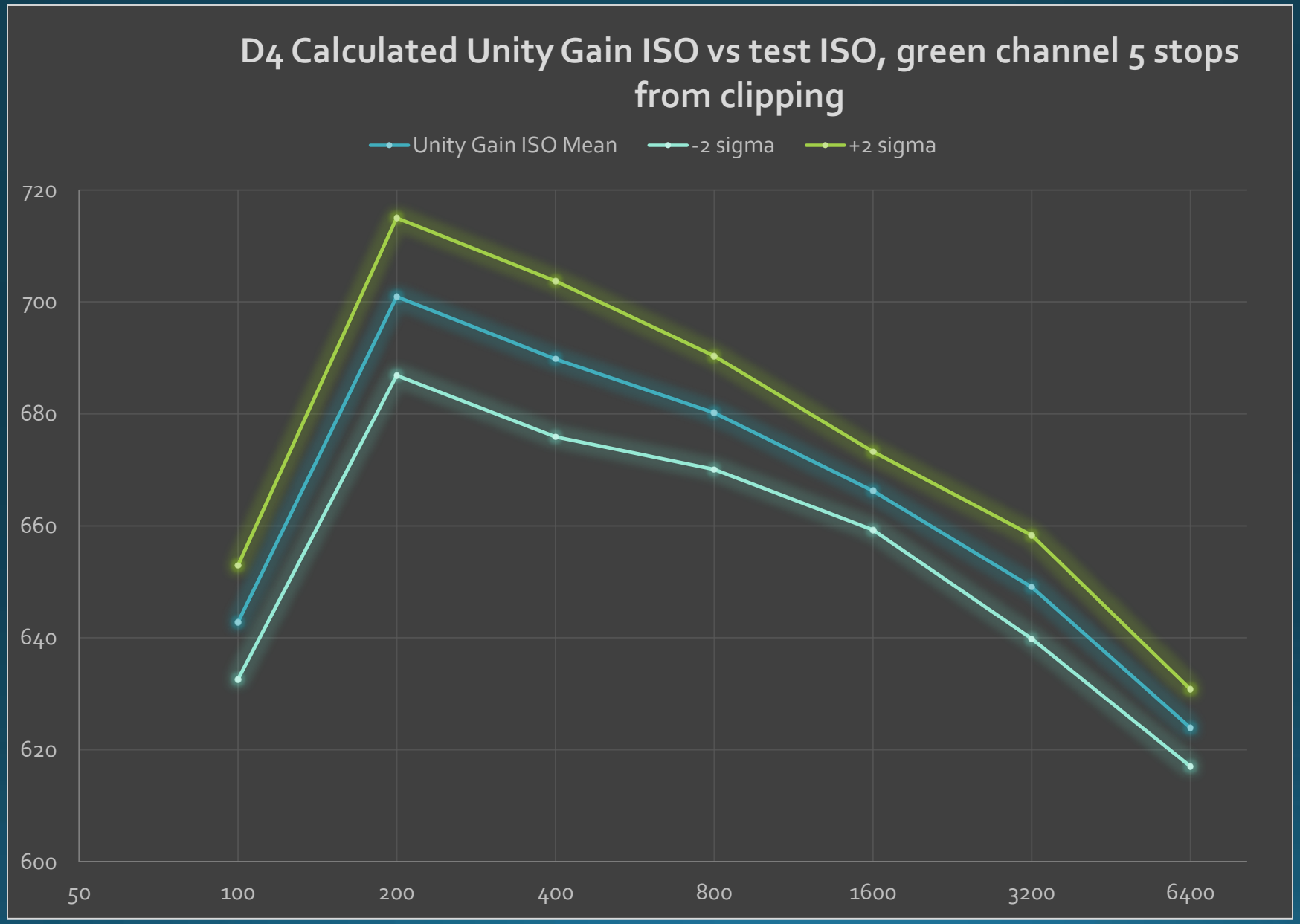


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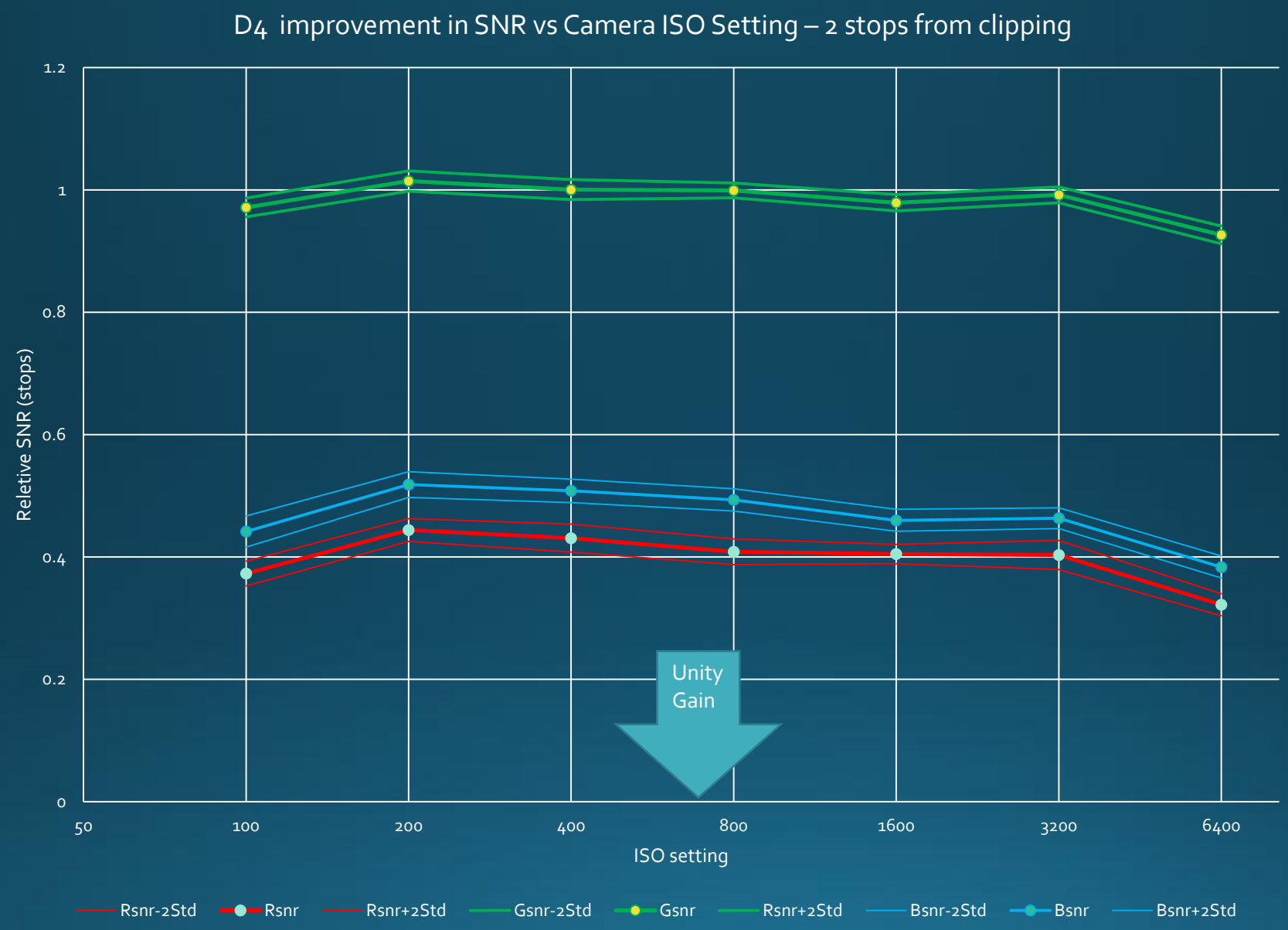


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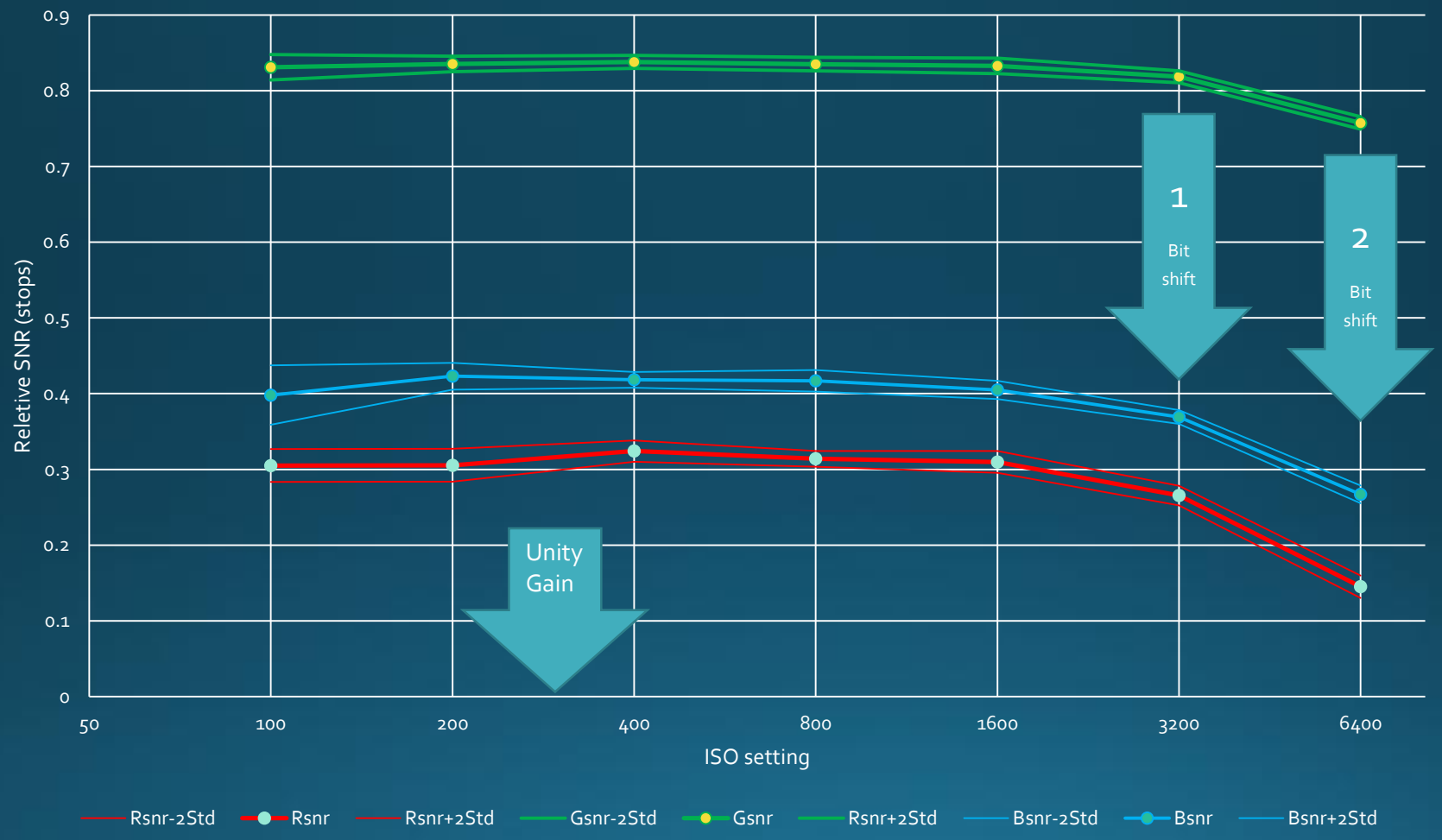
# D800E improvement in SNR vs Camera ISO Setting, 4 stops from clipping

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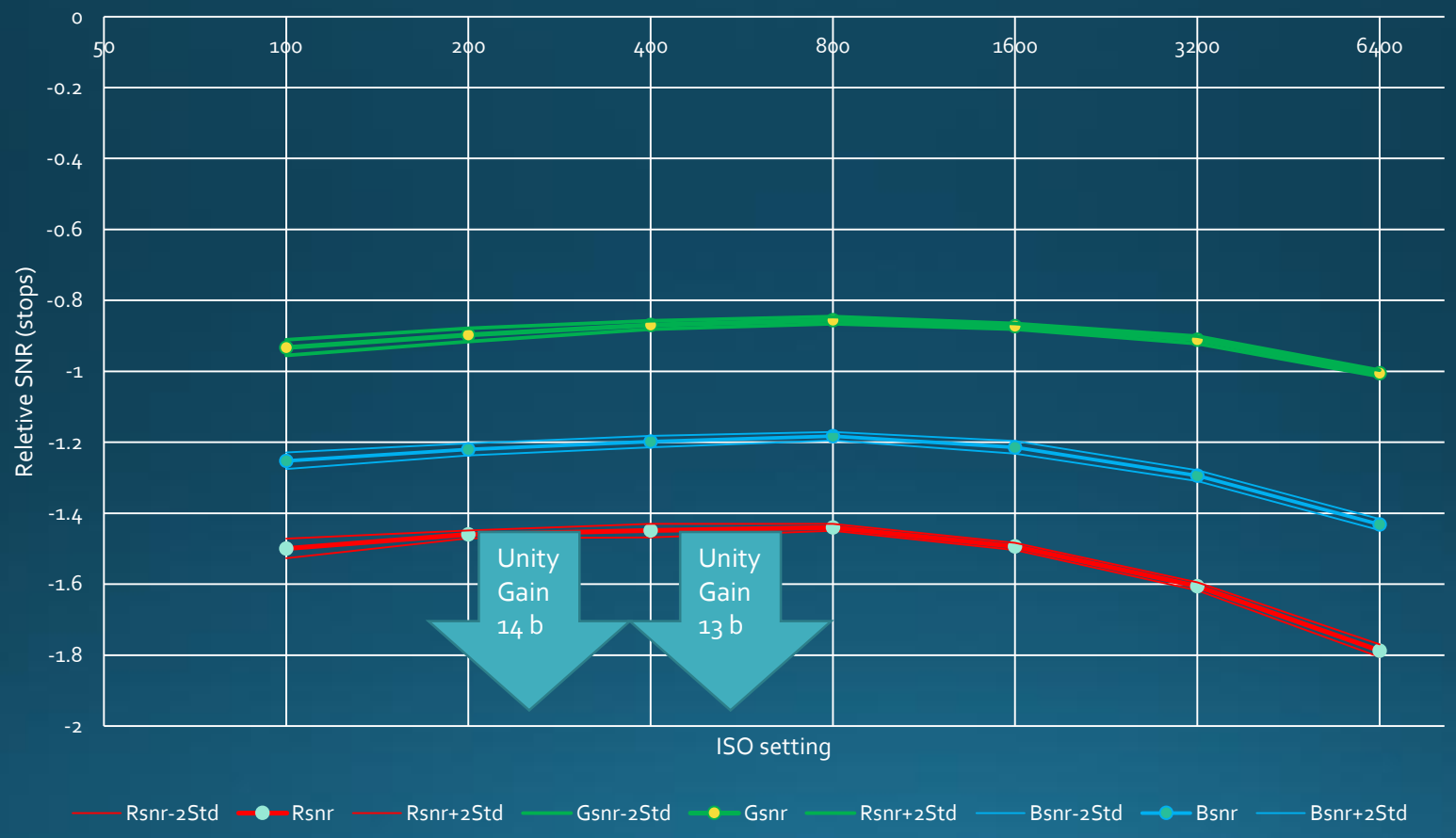
# RX-1 improvement in SNR vs ISO Setting, 5 stops from clipping

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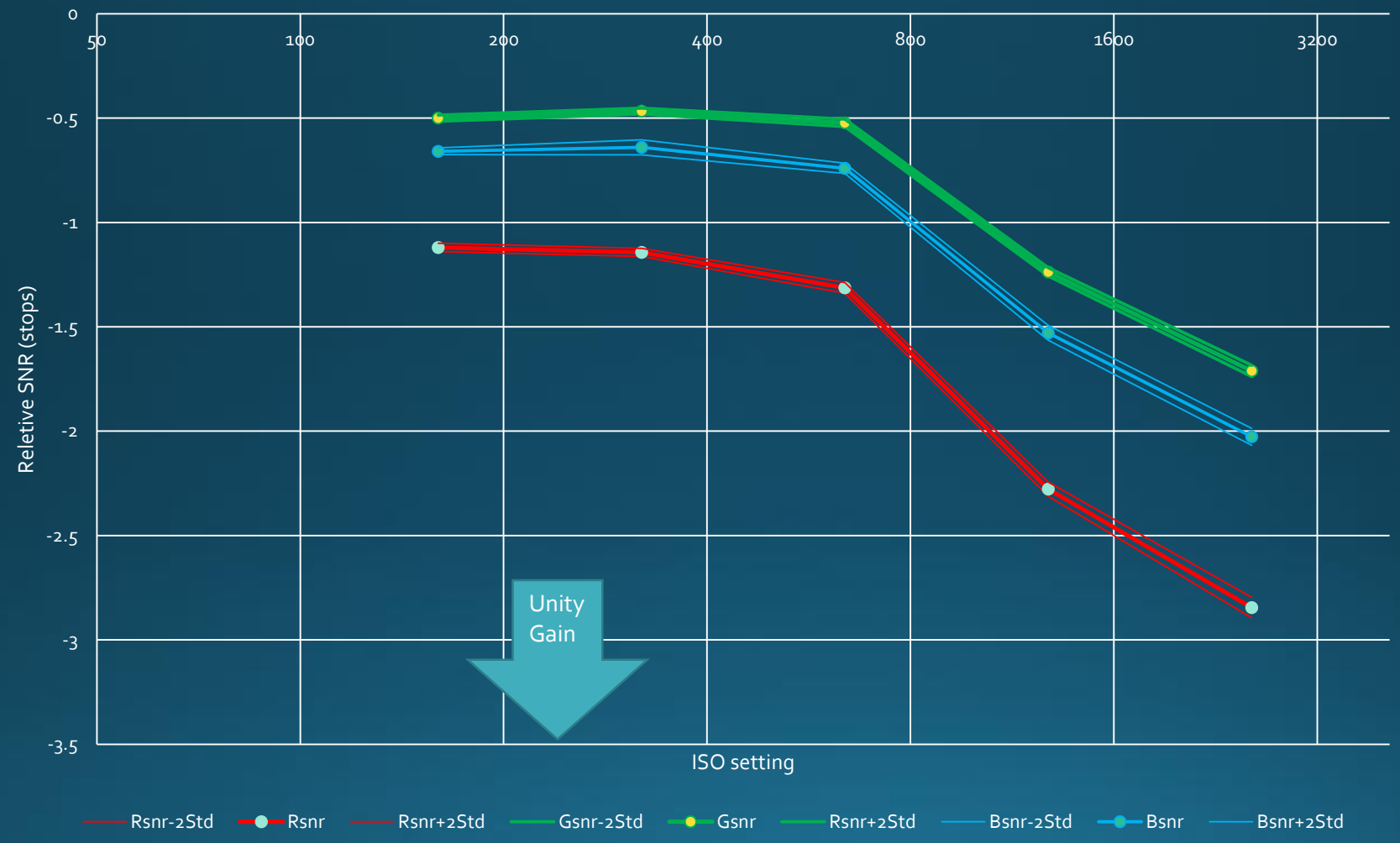
# M9 improvement vs ISO Setting, 5 stops from clipping

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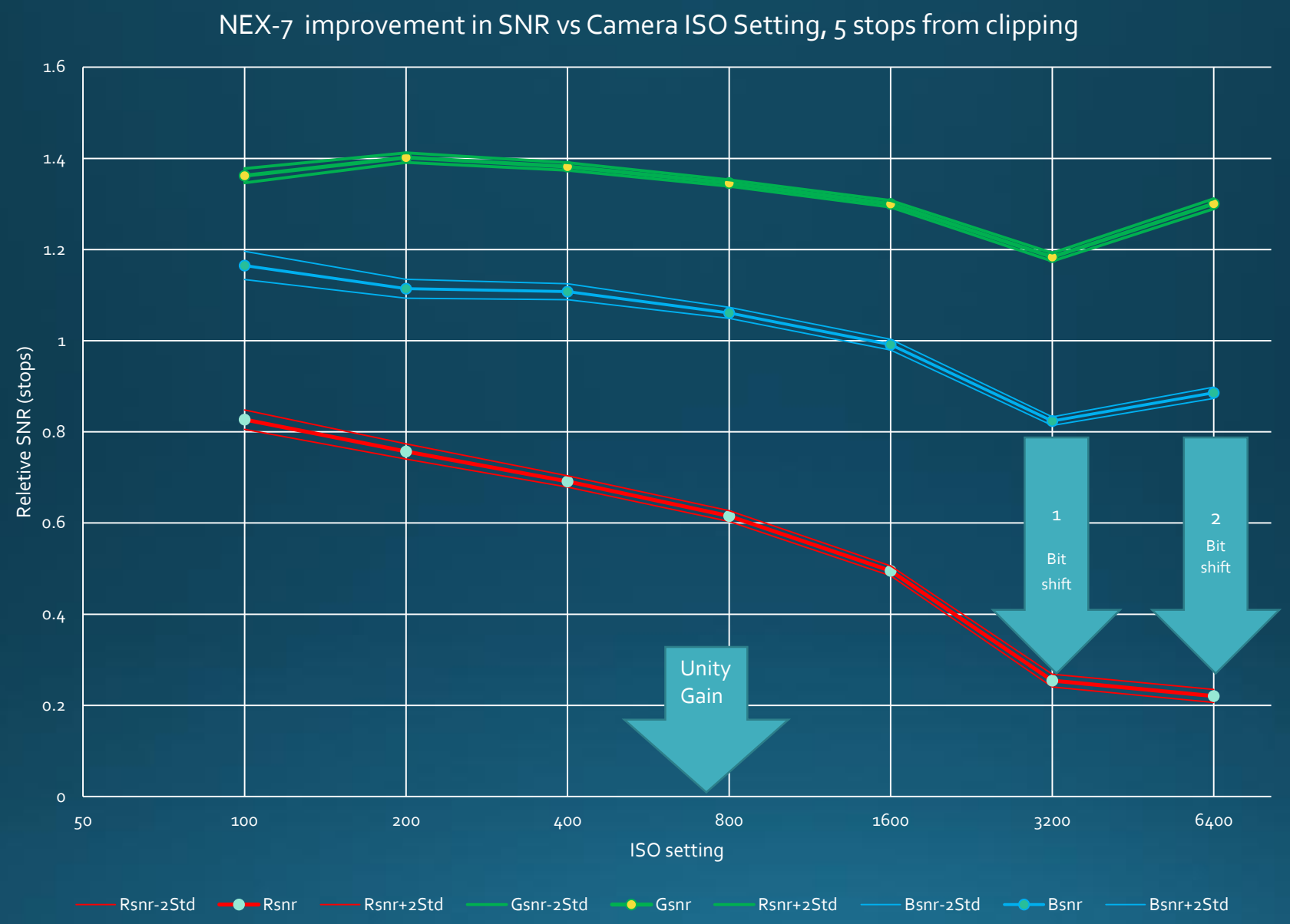


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# Which camera settings affect the raw RGB values?

- Color space – sRGB vs Adobe RGB
- White balance
- Contrast
- Brightness
- Sharpening

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# Which camera settings affect the raw RGB values?

- ~~Color space – sRGB vs Adobe RGB~~
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# Which camera settings affect the raw RGB values?

- ~~Color space – sRGB vs Adobe RGB~~
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# Which camera settings affect the raw RGB values?

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- ~~White balance~~
- ~~Contrast~~
- ~~Brightness~~
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# Which camera settings affect the raw RGB values?

- ~~Color space – sRGB vs Adobe RGB~~
- ~~White balance~~
- ~~Contrast~~
- ~~Brightness~~
- ~~Sharpening~~

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# Raw inspection programs

- DCRaw
- Rawdigger

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# Ordering lunch with a command line interface

- La Costena is a Mexican restaurant near the old Adobe development lab in Mountain View.

- **`burrito -time +:30 b+g+cc+jf+jf+sf+sc-sc+i"Black Beans"+n:2/Ross \ b+v:cc+g+cm+sc+i"no rice"/Kathie`**

- Will pick up order in 30 minutes. Ross wants two rice and bean (default) burritos with guacamole, cotija, double fresh jalepenos, fire salsa, no sour cream, and black beans. Kathie wants a Chile Colorado burrito with guacamole Monterey Jack cheese, sour cream, and no rice.

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# Raw conversion with DCRaw

- `dcraw -c crw_0001.crw | pnmtofits > crw_0001.fits`
- `dcraw -c crw_0001.crw | pnmtopng > crw_0001.png`
- `dcraw -c crw_0001.crw | ppmtobmp > crw_0001.bmp`
- `dcraw -c crw_0001.crw | cjpeg > crw_0001.jpeg`

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# DCRaw commands

- Usage: dcraw [OPTION]... [FILE]...

- -v Print verbose messages
- -c Write image data to standard output
- -e Extract embedded thumbnail image
- -i Identify files without decoding them
- -i -v Identify files and show metadata
- -z Change file dates to camera timestamp
- -w Use camera white balance, if possible
- -a Average the whole image for white balance
- -A <x y w h> Average a grey box for white balance
- -r <r g b g> Set custom white balance
- +M/-M Use/don't use an embedded color matrix
- -C <r b> Correct chromatic aberration
- -P <file> Fix the dead pixels listed in this file
- -K <file> Subtract dark frame (16-bit raw PGM)
- -k <num> Set the darkness level
- -S <num> Set the saturation level
- -n <num> Set threshold for wavelet denoising
- -H [0-9] Highlight mode (0=clip, 1=unclip, 2=blend, 3+=rebuild)
- -t [0-7] Flip image (0=none, 3=180, 5=90CCW, 6=90CW)
- -o [0-5] Output colorspace (raw,sRGB,Adobe,Wide,ProPhoto,XYZ)
- -o <file> Apply output ICC profile from file
- -p <file> Apply camera ICC profile from file or "embed"
- -d Document mode (no color, no interpolation)
- -D Document mode without scaling (totally raw)
- -j Don't stretch or rotate raw pixels
- -W Don't automatically brighten the image
- -b <num> Adjust brightness (default = 1.0)
- -q [0-3] Set the interpolation quality
- -h Half-size color image (twice as fast as "-q 0")
- -f Interpolate RGGB as four colors

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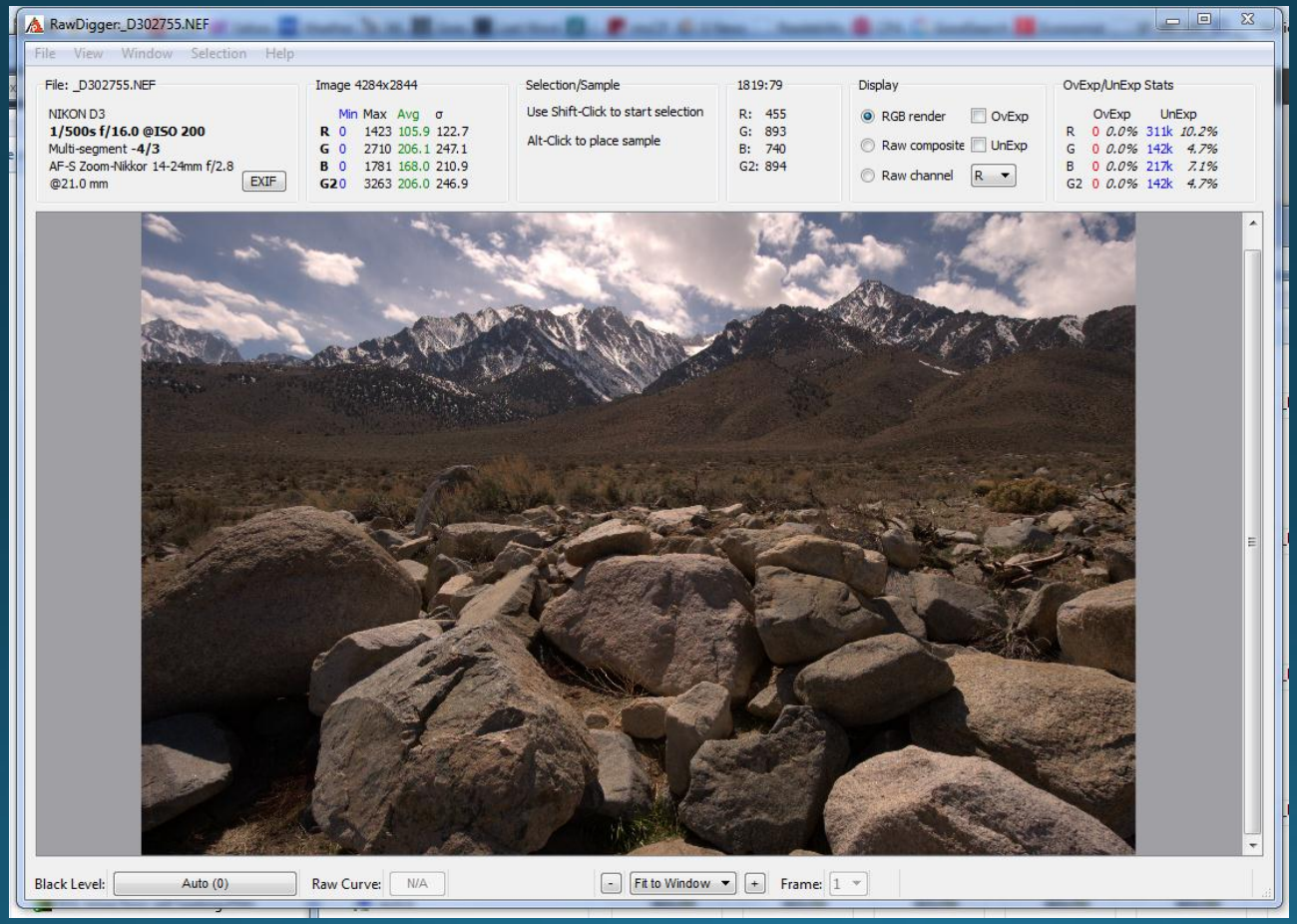
# RawDigger GUI

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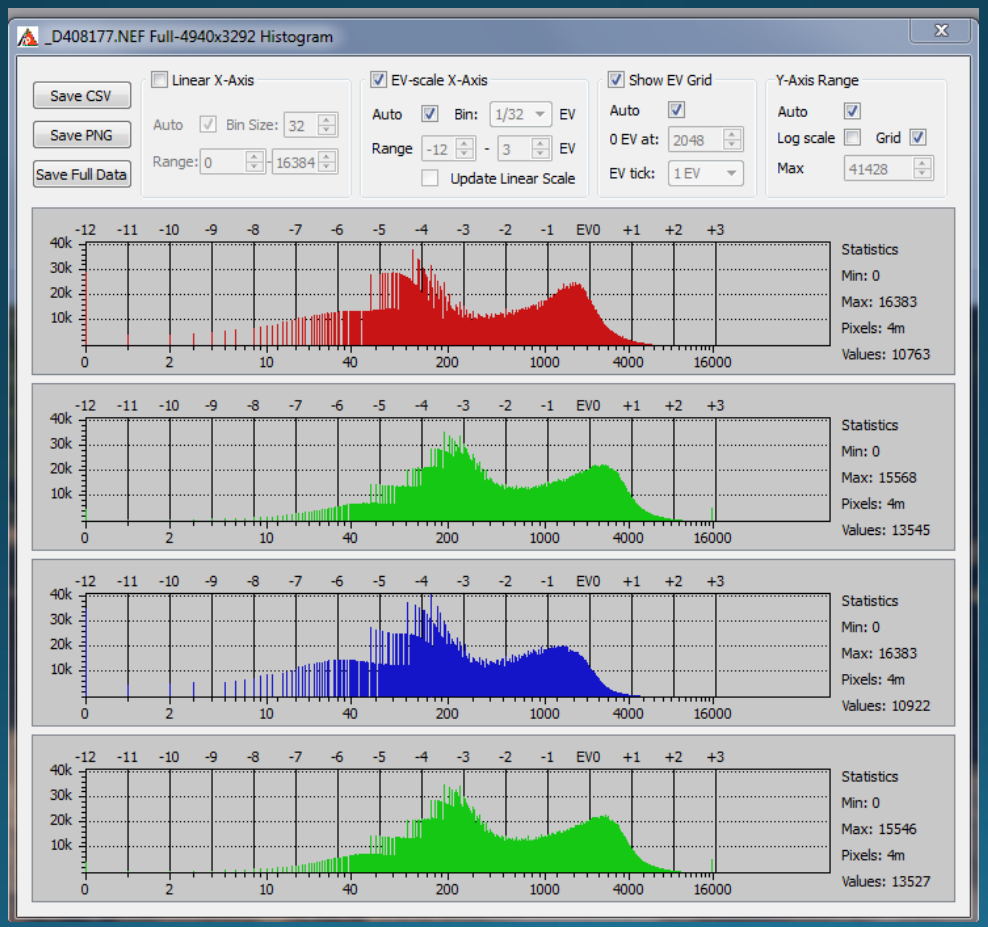
# RawDigger Histograms

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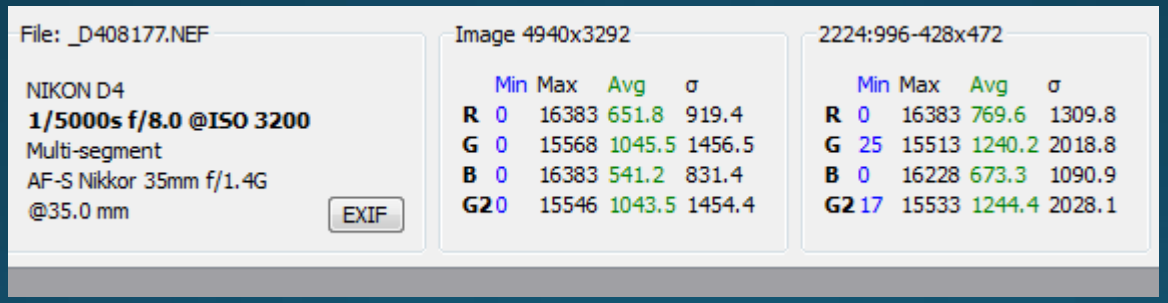
# RawDigger Statistics

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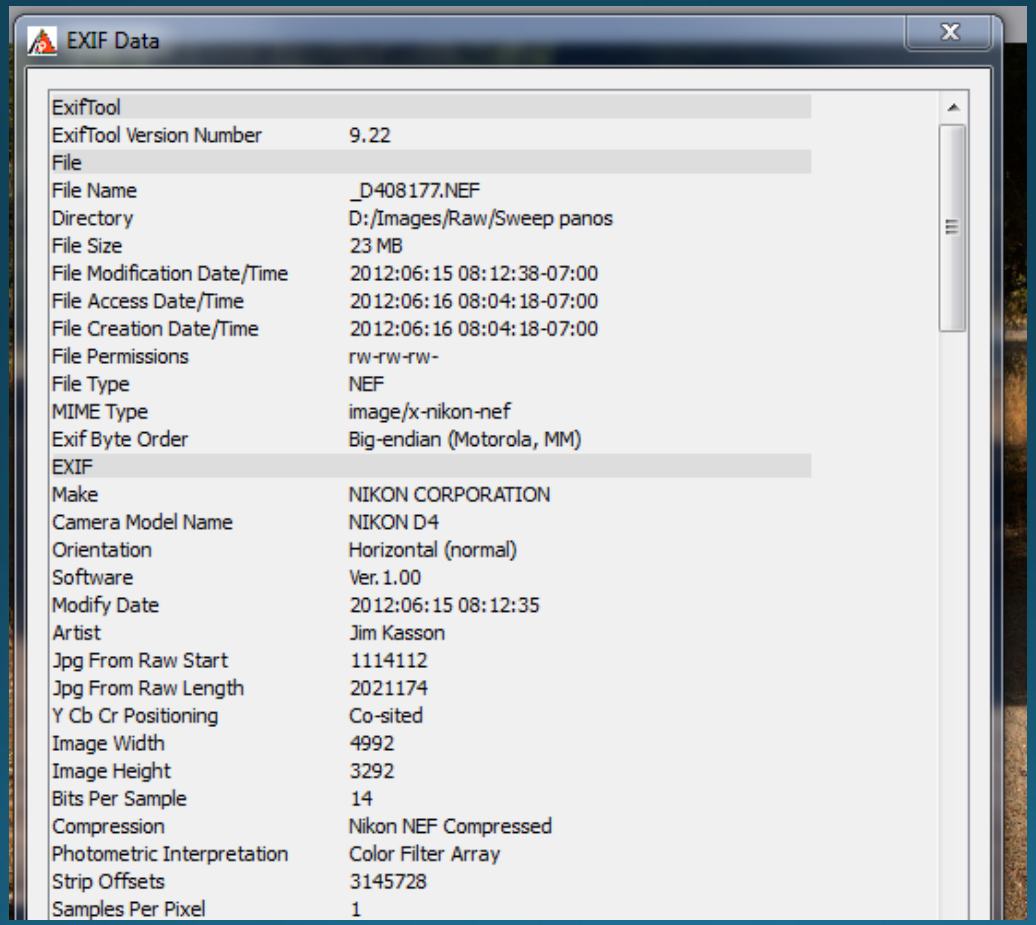
# RawDigger EXIF data



EXIF Data

| | |
|---|---|
| ExifTool | |
| ExifTool Version Number | 9.22 |
| File | |
| File Name | _D408177.NEF |
| Directory | D:/Images/Raw/Sweep panos |
| File Size | 23 MB |
| File Modification Date/Time | 2012:06:15 08:12:38-07:00 |
| File Access Date/Time | 2012:06:16 08:04:18-07:00 |
| File Creation Date/Time | 2012:06:16 08:04:18-07:00 |
| File Permissions | rw-rw-rw- |
| File Type | NEF |
| MIME Type | image/x-nikon-nef |
| Exif Byte Order | Big-endian (Motorola, MM) |
| EXIF | |
| Make | NIKON CORPORATION |
| Camera Model Name | NIKON D4 |
| Orientation | Horizontal (normal) |
| Software | Ver. 1.00 |
| Modify Date | 2012:06:15 08:12:35 |
| Artist | Jim Kasson |
| Jpg From Raw Start | 1114112 |
| Jpg From Raw Length | 2021174 |
| Y Cb Cr Positioning | Co-sited |
| Image Width | 4992 |
| Image Height | 3292 |
| Bits Per Sample | 14 |
| Compression | Nikon NEF Compressed |
| Photometric Interpretation | Color Filter Array |
| Strip Offsets | 3145728 |
| Samples Per Pixel | 1 |

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# A few raw processors

- AfterShot Pro
- Aperture
- Canon Digital Photo Professional
- Capture 1
- DxO Optics Pro
- Hasselblad/Imacon Phocus
- Lightroom/Adobe Camera Raw
- Nikon Capture NX2
- Photo Ninja
- Raw Developer (Mac only)
- Raw Photo Processor (Mac only)
- Raw Therapee

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# Where to sharpen

- When demosaicing: *capture* sharpening
- At native resolution in working color space: *judgment* sharpening
- At print resolution: *output* sharpening

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