Challenges of HDR imaging in Automotive Environment

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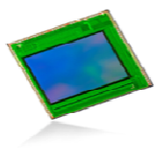
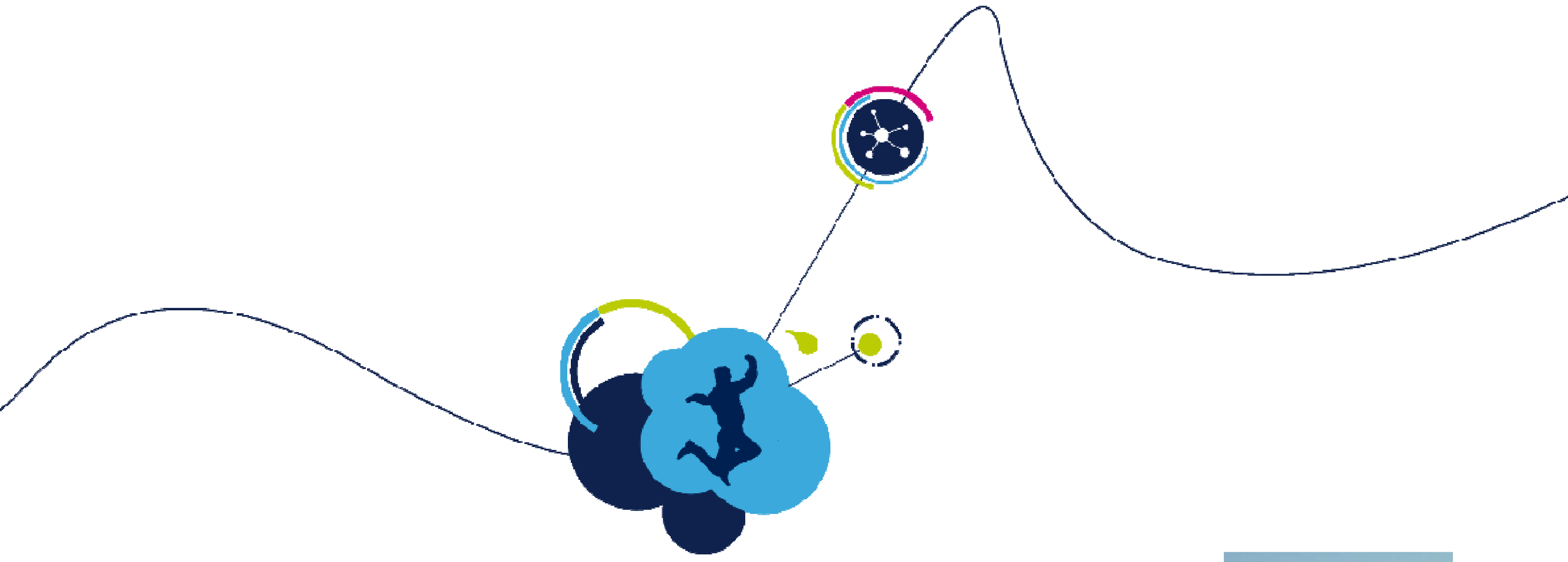


Contents

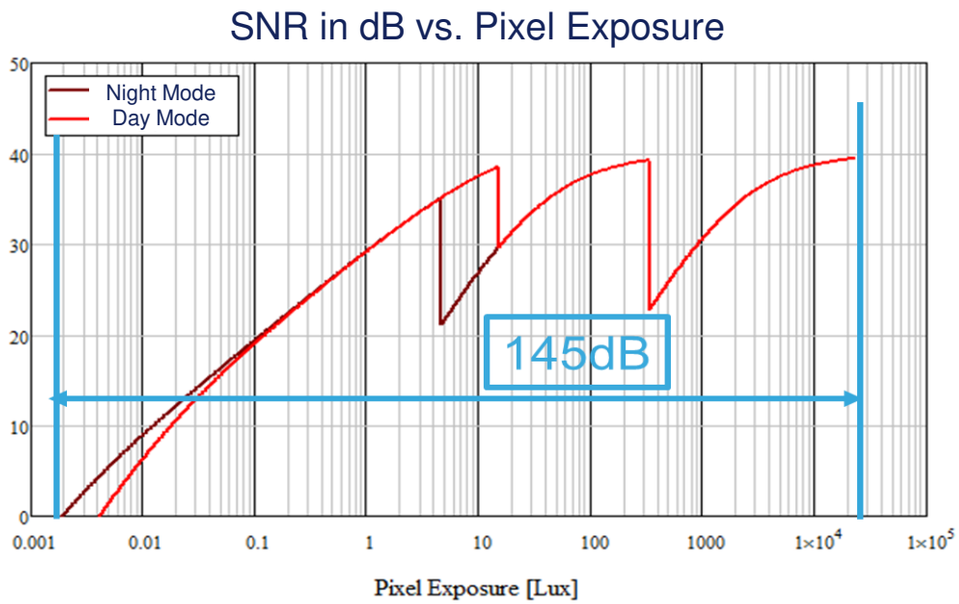
- Flicker Free
  - How does it work?
  - What makes the residual modulation?
  - What can a Flicker Free Camera Perceive?
- High Dynamic Range, SNR
  - What does it tell me, what do I need?
  - ISP – Impacting SNR and Usable Dynamic Range
  - Xtreme Dynamic Range Use Cases
- Conclusions

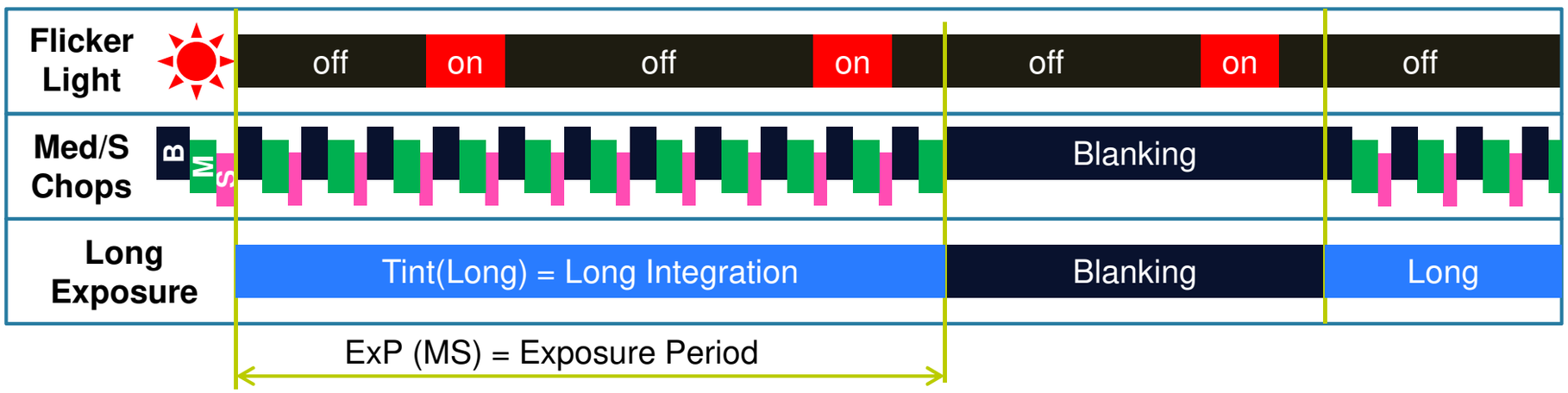


Flicker Free – How does it work?

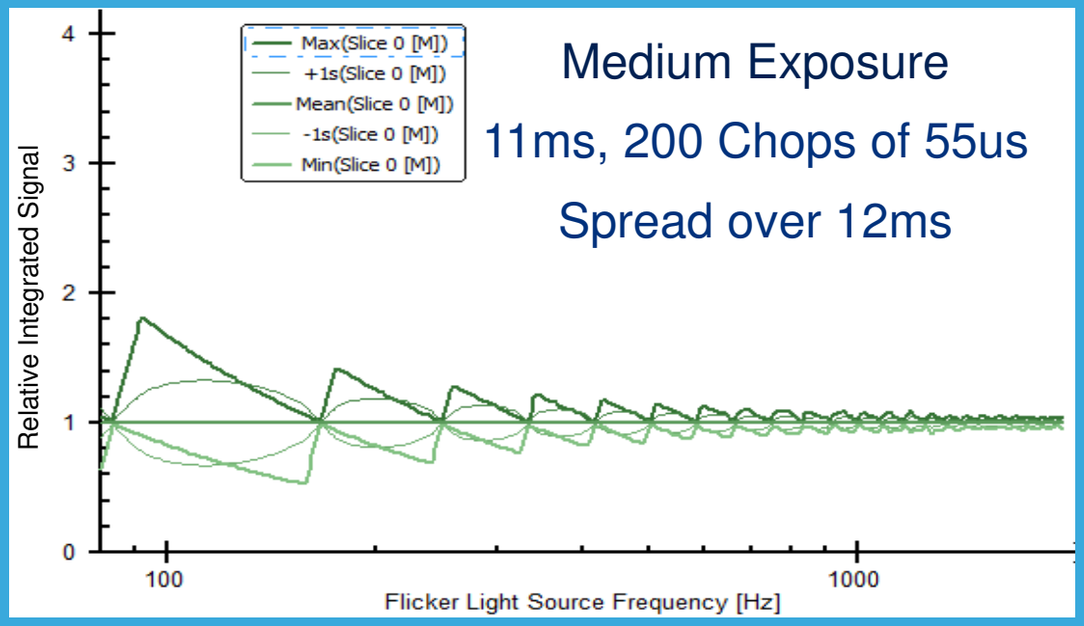
ST Flicker Free 145dB Pixel – Recap

- Flicker Free Image Sensor with patented 145dB 3.2µm pixel in proprietary CDTI technology
- Long Integration undisturbed: Low Light Performance
- Second photo diode delivers Med/Short information in parallel
- Cut M/S into many (200) short samples = chops

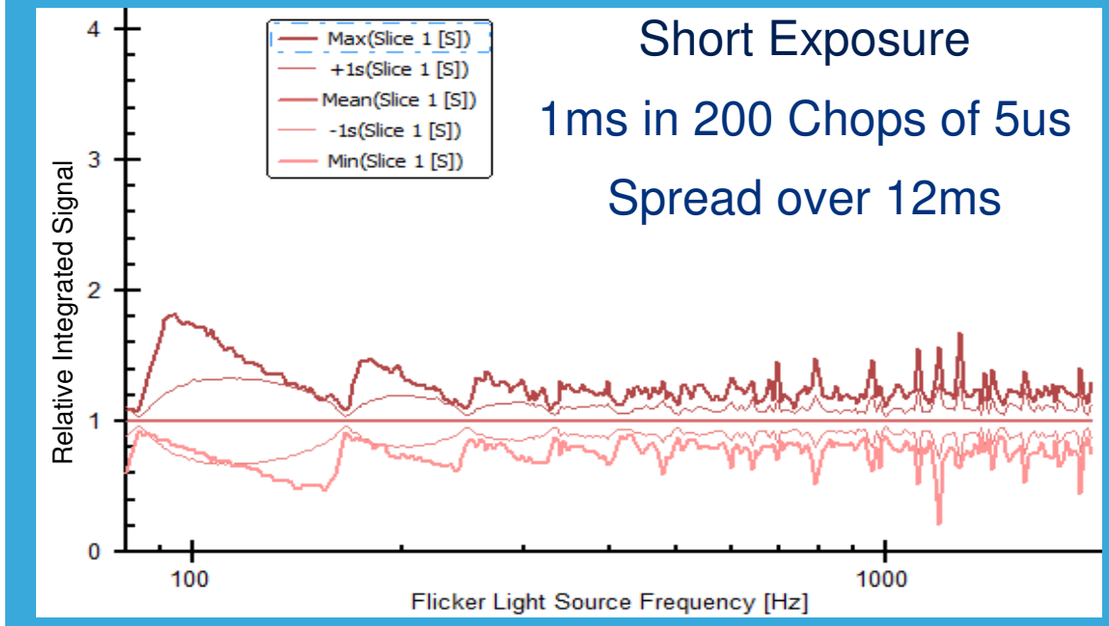




ST Flicker Free Pixel –Frequency Responses



- f: 80Hz … 2kHz, Duty Cycle: 10%
- Min, Max, Mean and +/- 1 Sigma across 111 Phases: from 0º to 357º
- The sensor never misses a light source, whatever the phase or frequency



- Some residual modulation remains inevitably, here shown for 10% D.C.
- Randomization mitigates aliasing effects at high frequencies
- The safety issue solved

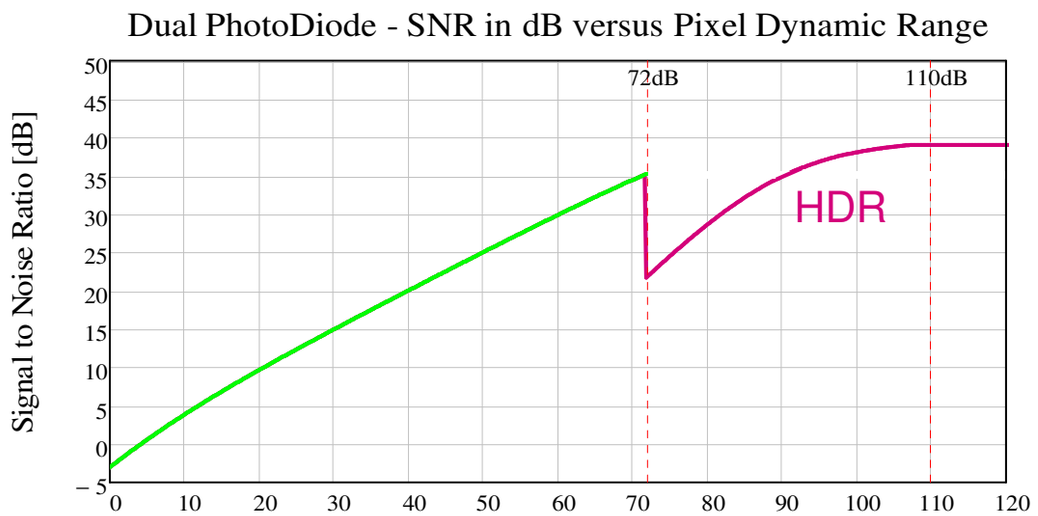
Comparison With / Without FF

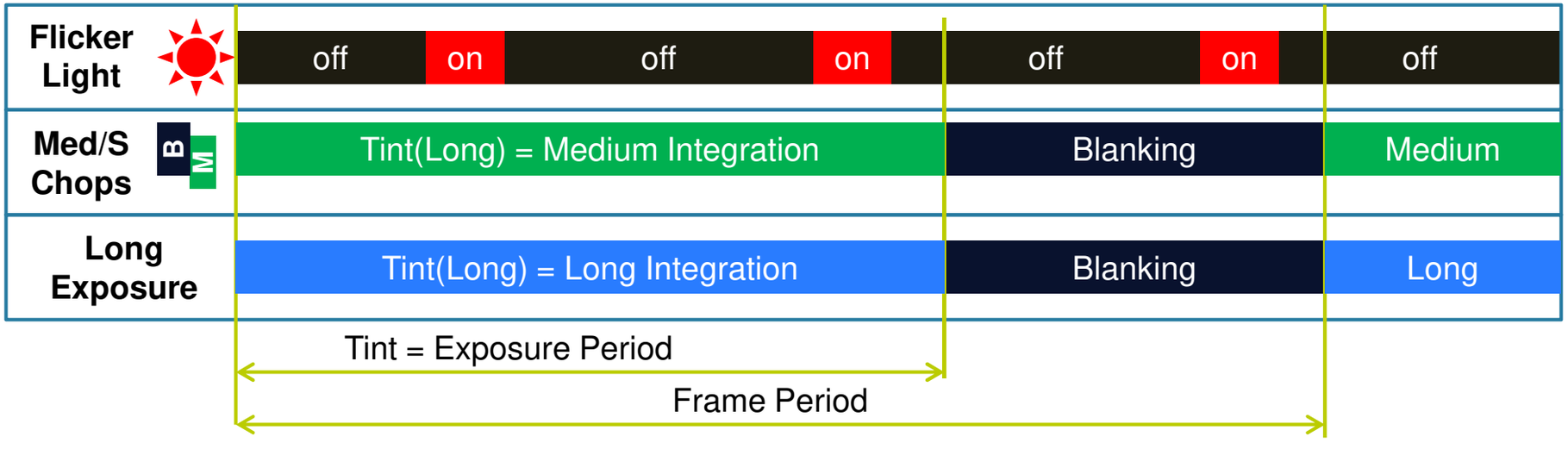
- ‘Conventional’ HDR Sensor

- Flicker Free HDR Sensor

Alternative Ways to HDR Flicker Free – 1

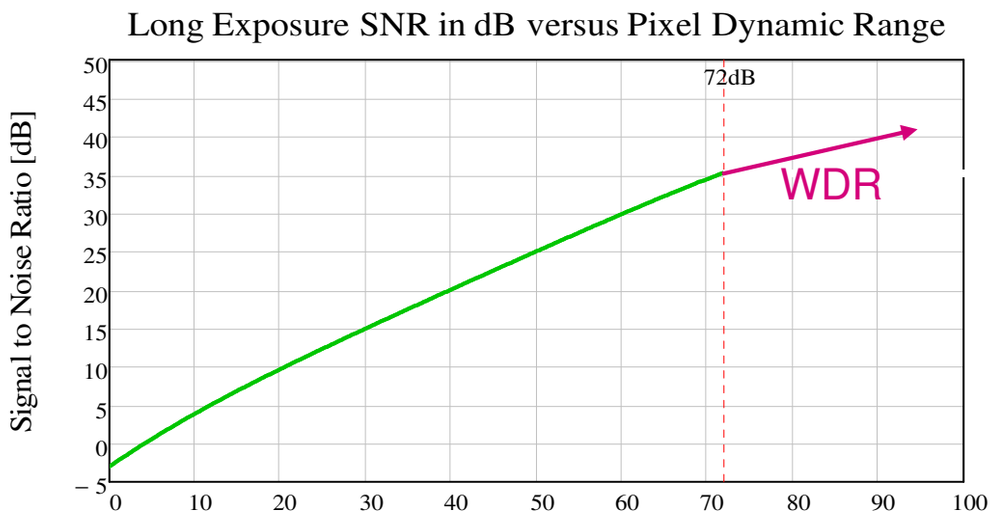
- Long Integration undisturbed: Low Light Performance
- Second photo diode delivers MEDIUM information in parallel
- Chopping not Mandatory: But then the shortest Integration Time Fixed for Flicker Free Operation



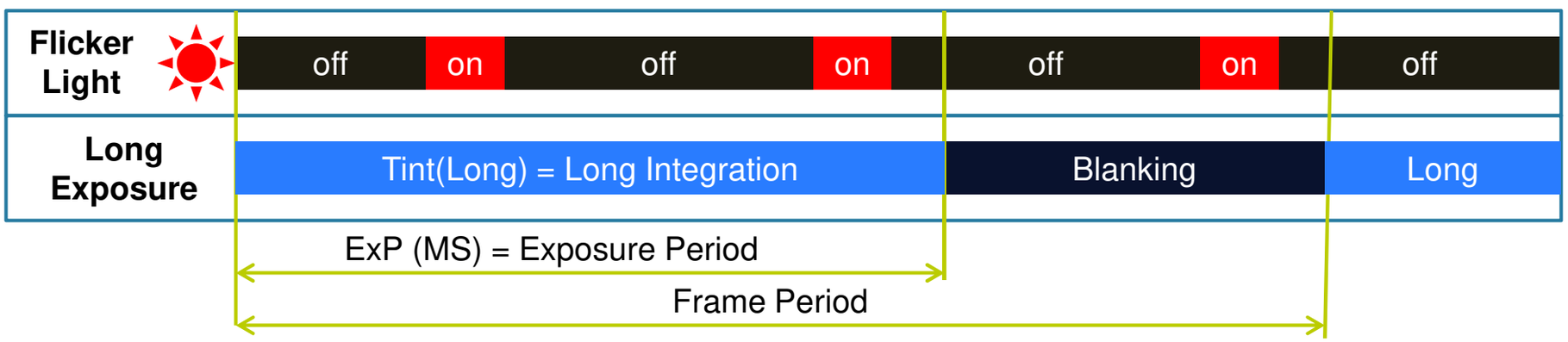


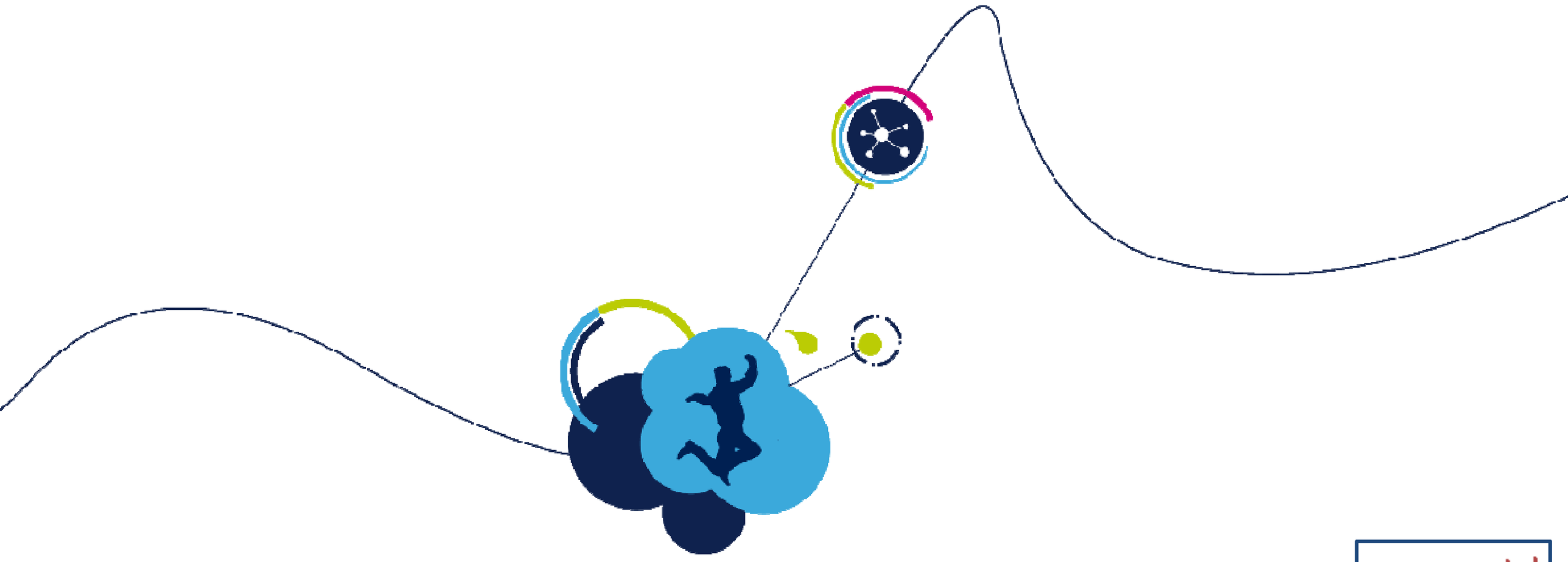
Alternative Ways to HDR Flicker Free - 2

- One Single Long Integration Time does it all:
  - Good Flicker Coverage, but only at Tint>12ms.
- Challenge is to achieve High Dynamic Range:
  - 90+ dB reported is very respectable but … is it enough?

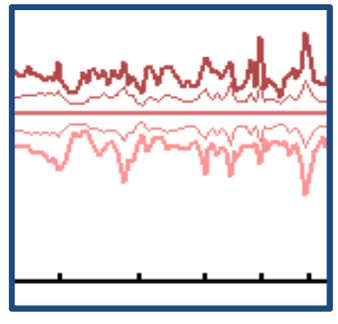


- For day light, integration time need to be <12ms
  - Flicker Coverage is lost



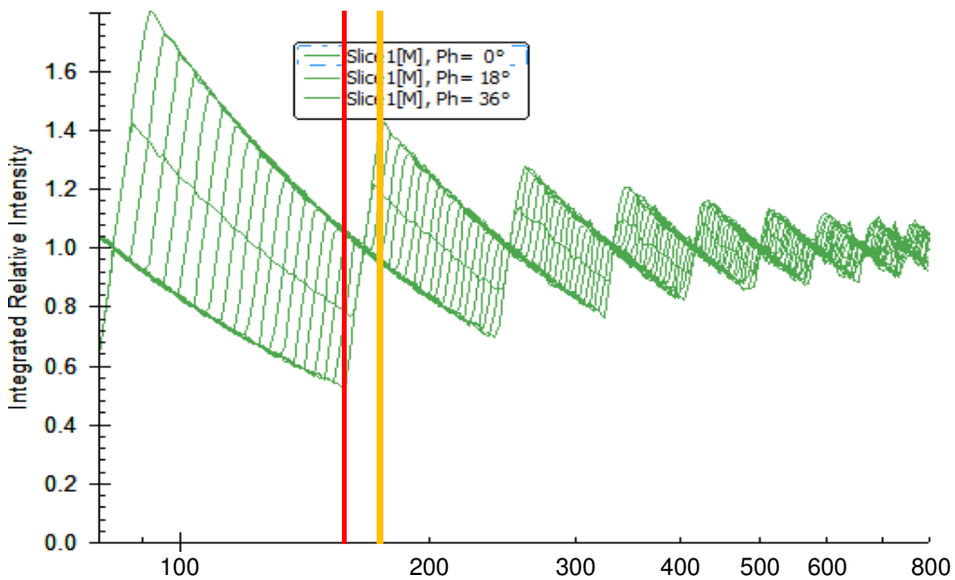


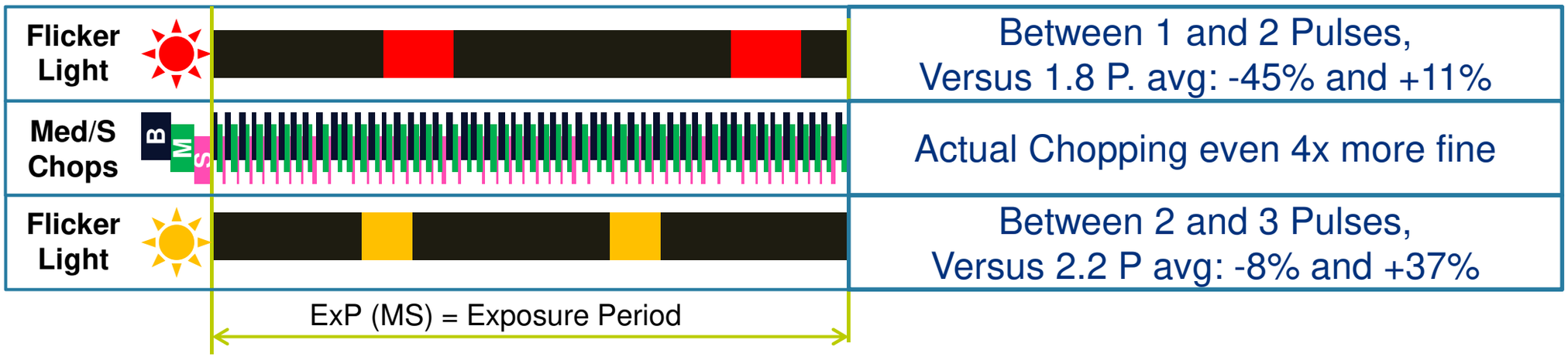
What makes the residual modulation?



Residual Flicker / Frame to Frame

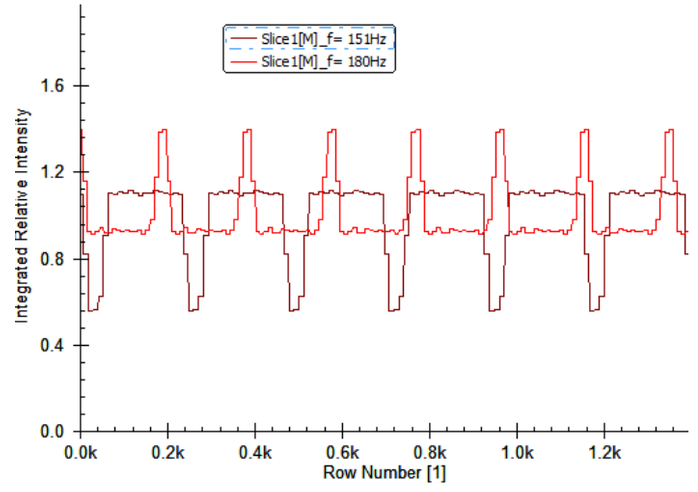
- Some residual modulation is inevitably still there, that is physics.
  - The LED change apparent brightness frame 2 frame
  - Larger ratio T(ExP) / T(PWM) reduce the amplitude!
- Compressed for visual application to a low amplitude, since this happens in the highlights of the scene
- Machine vision algorithms may sense the modulation and deduce information?

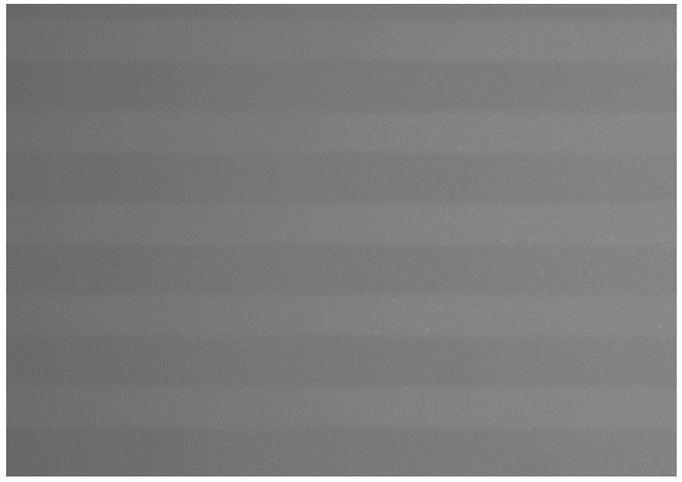




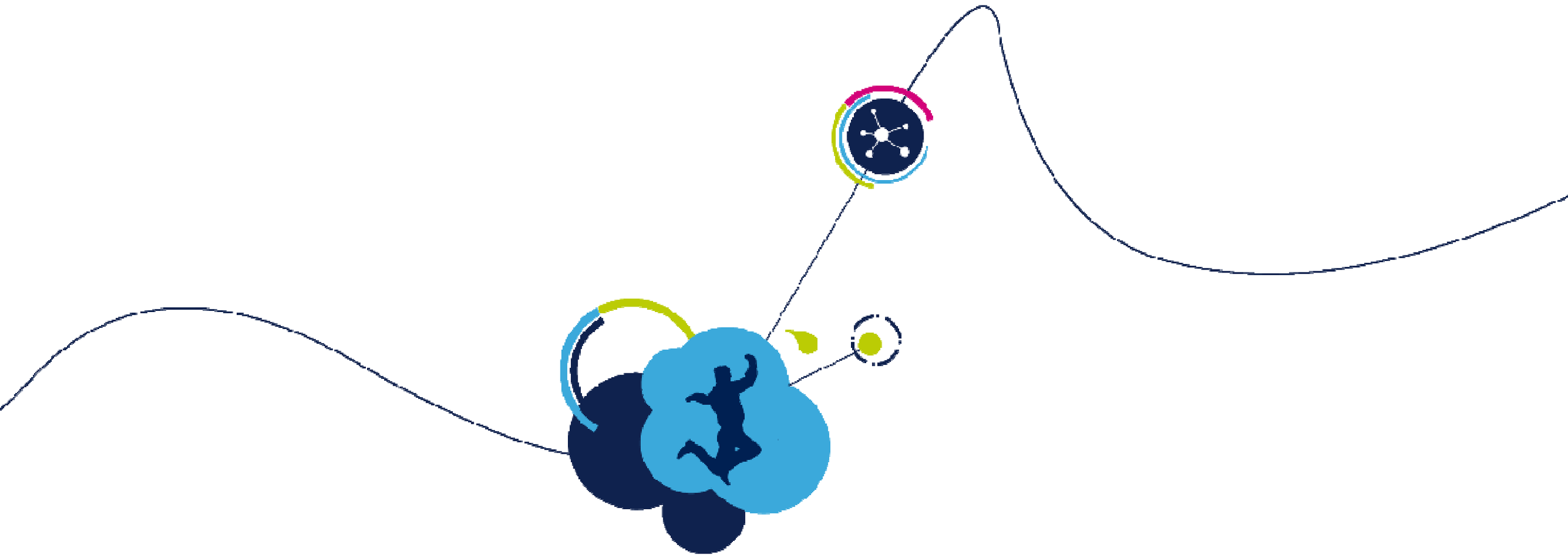
Residual Flicker / Inside a Frame

- Entire ambient light intensity is changing, is modulated.
  - LED light is 100% AM, at f >> 50Hz
  - Rolling shutter exposure samples at different phases.
  - Modulation leads to horizontal banding top to bottom
- Transition of stripes can be steep
  - Human eye is more sensitive to these abrupt jumps even at low amplitude
- Stripes can move where frequencies not in sync
- This is a task for the System Engineer to
  - Tweak the chopping period to be …
  - a multiple of the LED flicker, in case it comes from the own car for ex.
  - Measure the flickering frequencie(s) in the scene …





Example Snapshot

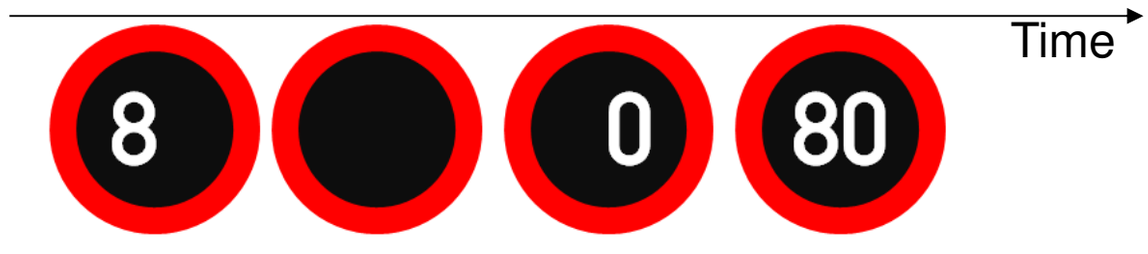


What can a Flicker Free Camera Perceive?

New Ghost Kids on the block

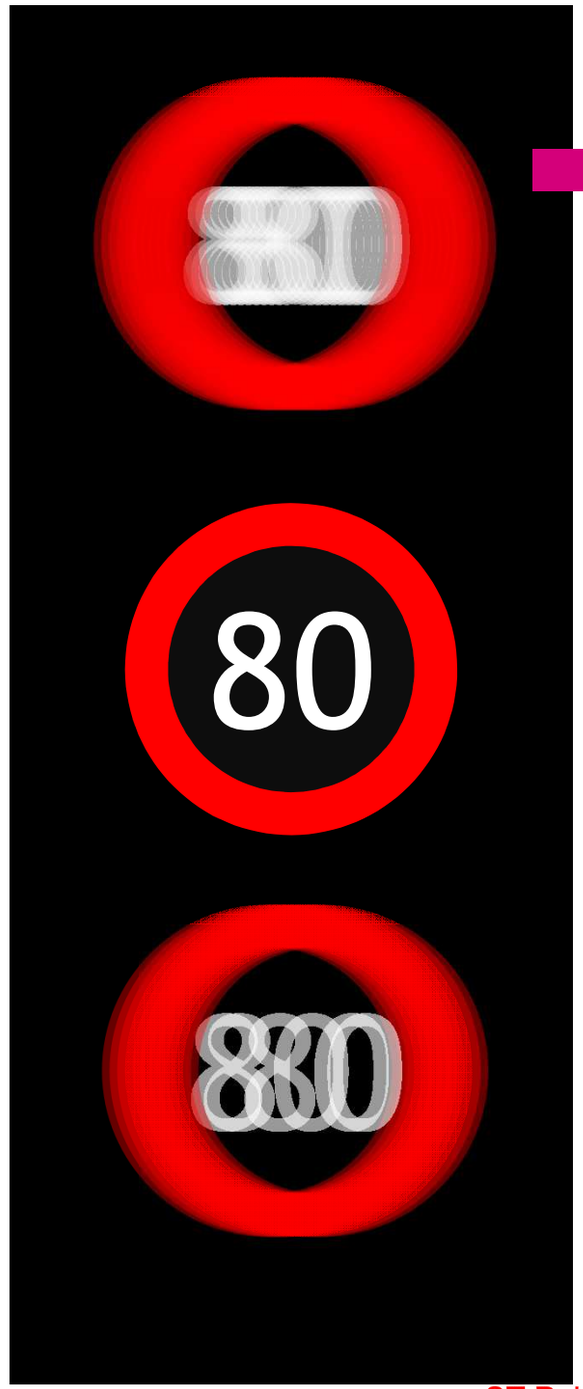
Motion Blur + Flickering

- Movement of static objects = blur
- Active Road Sign:



- Flickering + motion together:
  - example sequence: 80, 8 , , , , , 0, 80

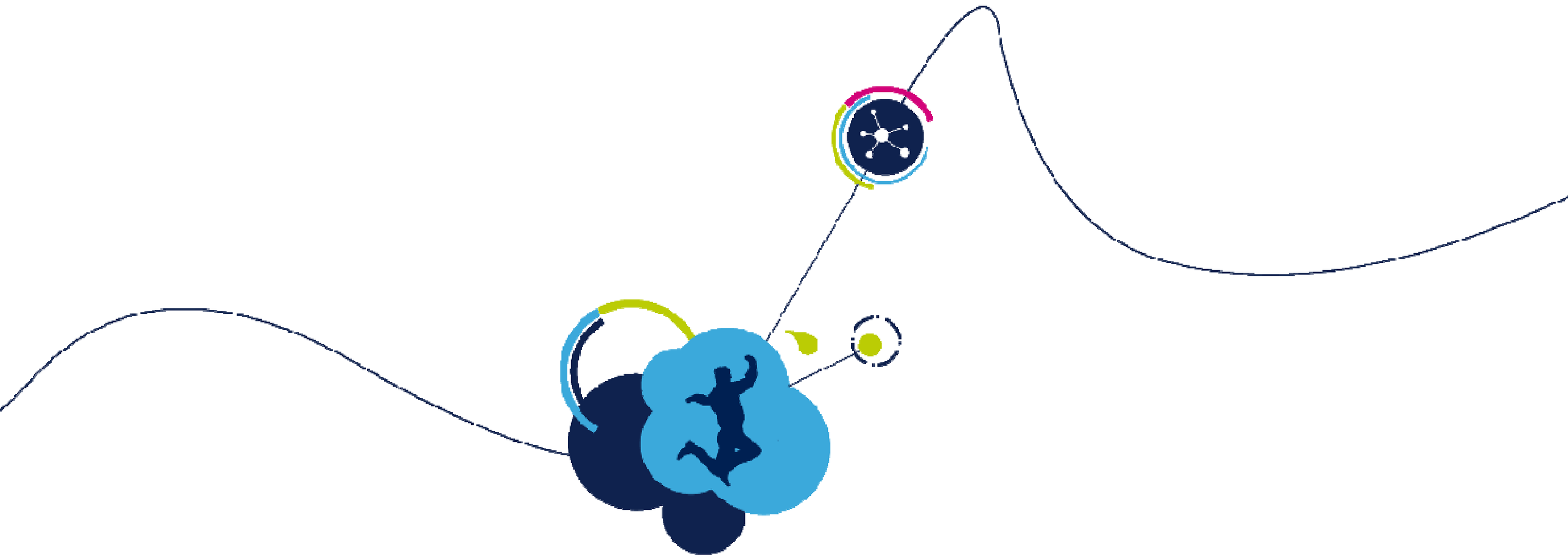
- Inherent to All Flickering Free:
  - Algos to make sure the car does not read 800km/h



Grab the Information at the Right Time

A few Frames Earlier: all ok

Minimize Vibrations, Remember information from before



What can a Flicker Free Camera Perceive? Part 2

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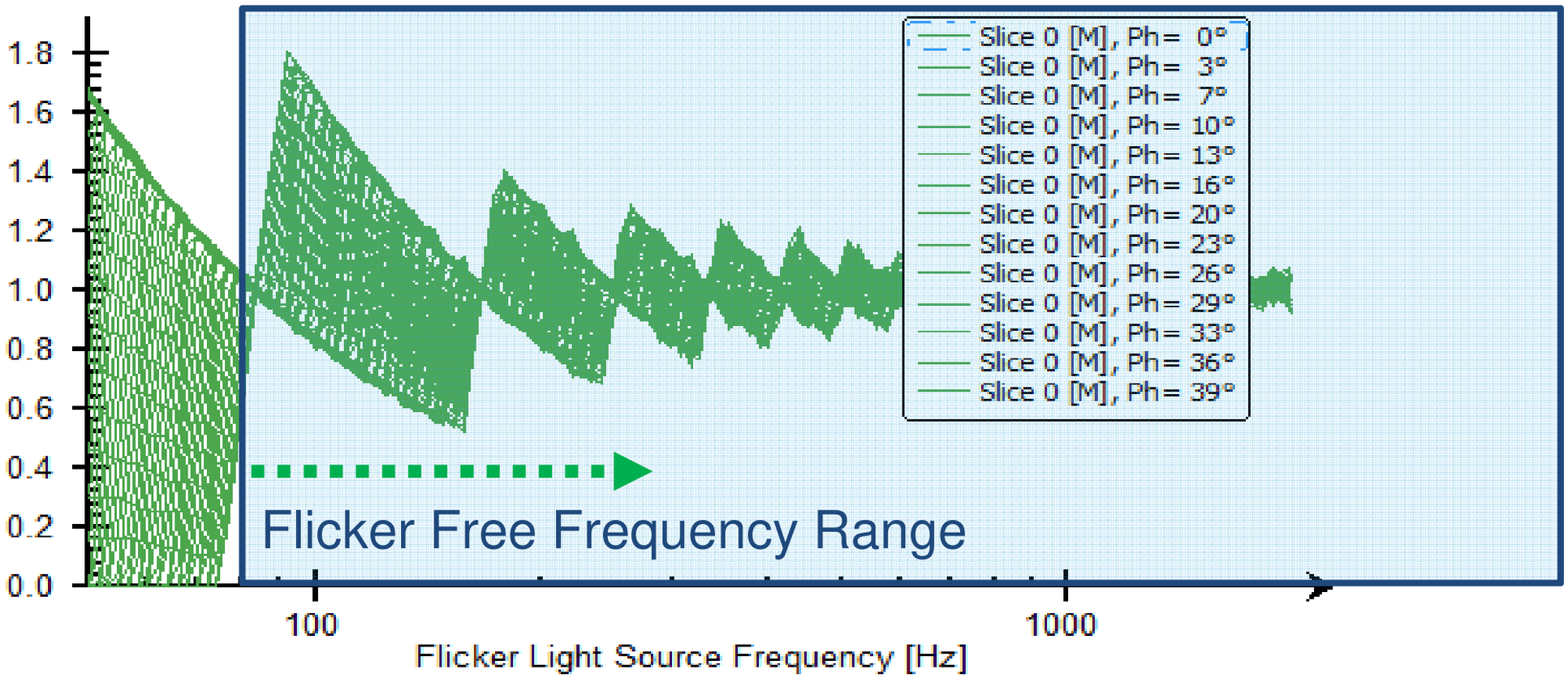
Fast Movement

- Blur due to long integration time

Flicker Free = Motion Blur ?

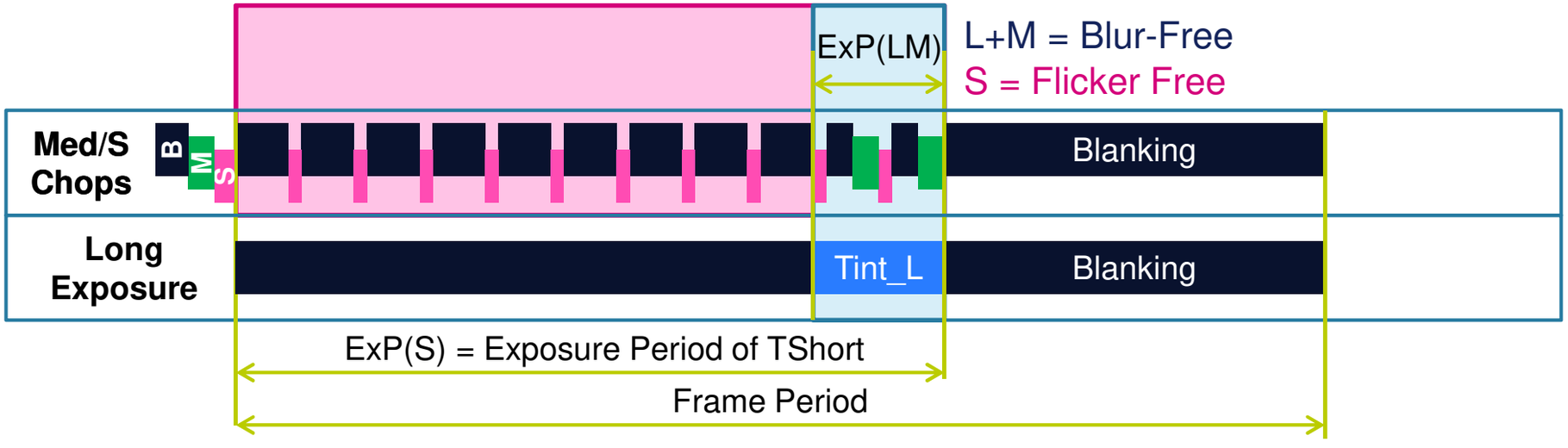
- Flicker free capture of Frequencies >80Hz, requires 12.5ms PEx
  - → Motion Blur higher than usual, not acceptable for some applications



- Does it mean: Flicker Free and Blur-Free do not like each other??

ST Hybrid-Mode: Flicker-Free & Blur-Free

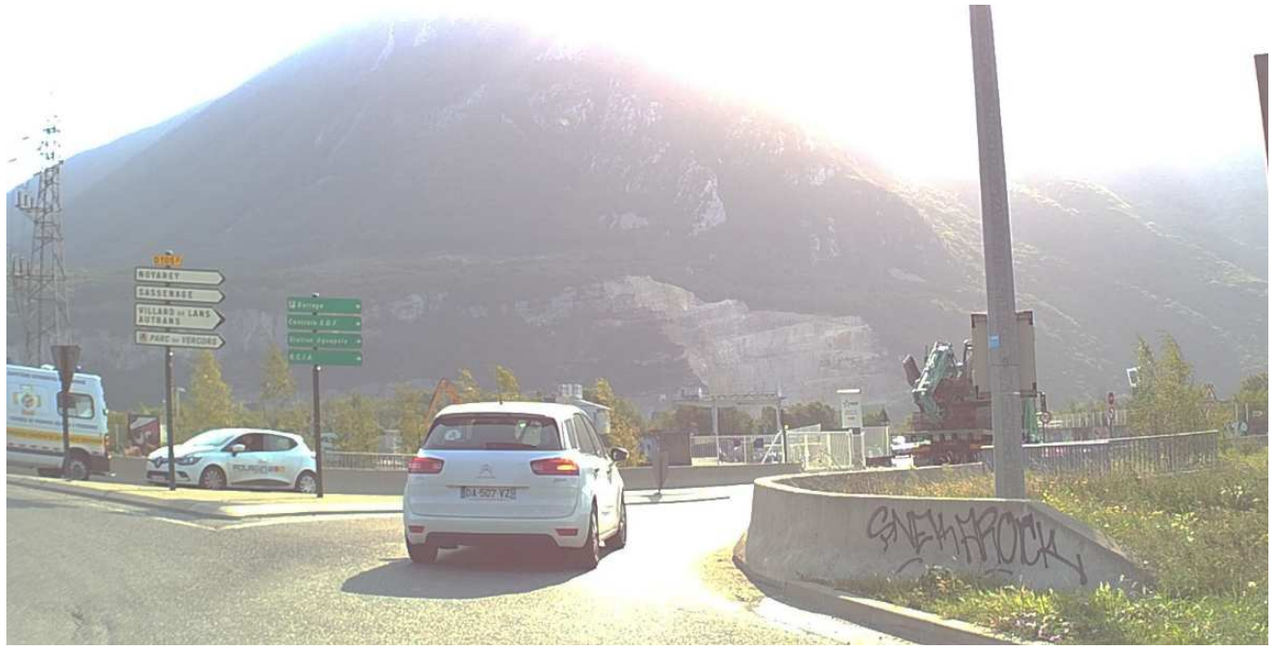
- Hybrid Mode: 2 Frames simultaneously
- LONG merged with MEDIUM: short ExP = 120dB blur free, ghost free
- SHORT: full Exposure Period = 60dB Flicker Free

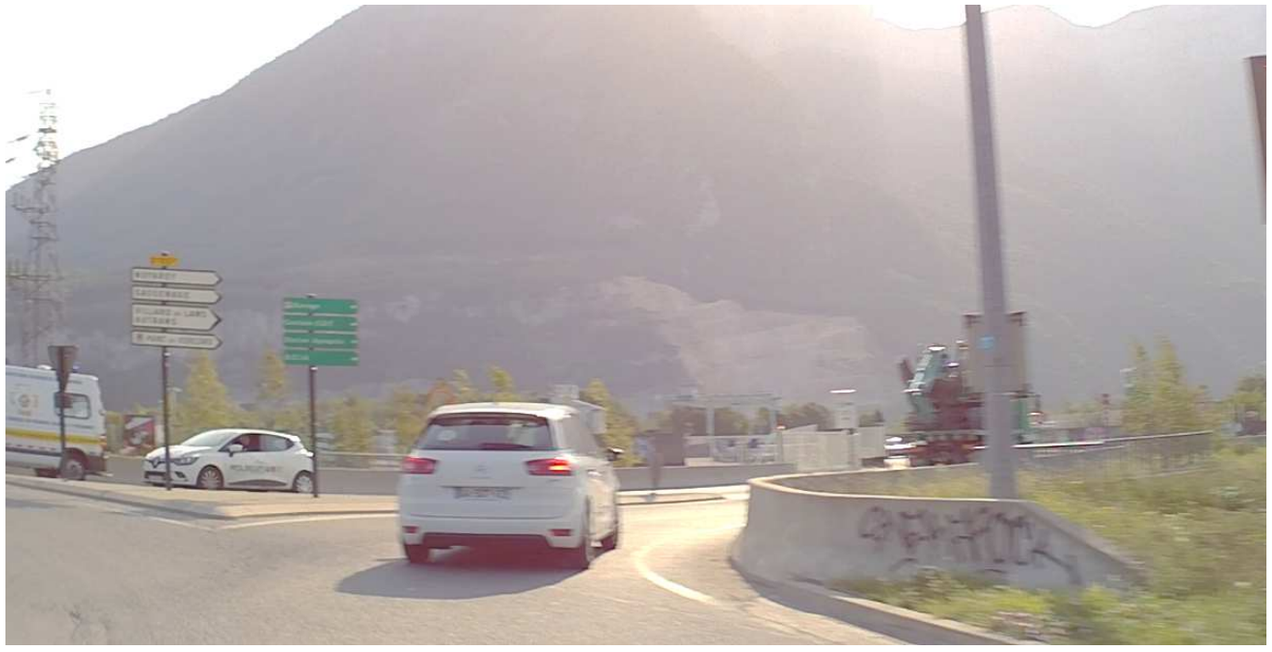


Previews of Hybrid Mode with VG6769

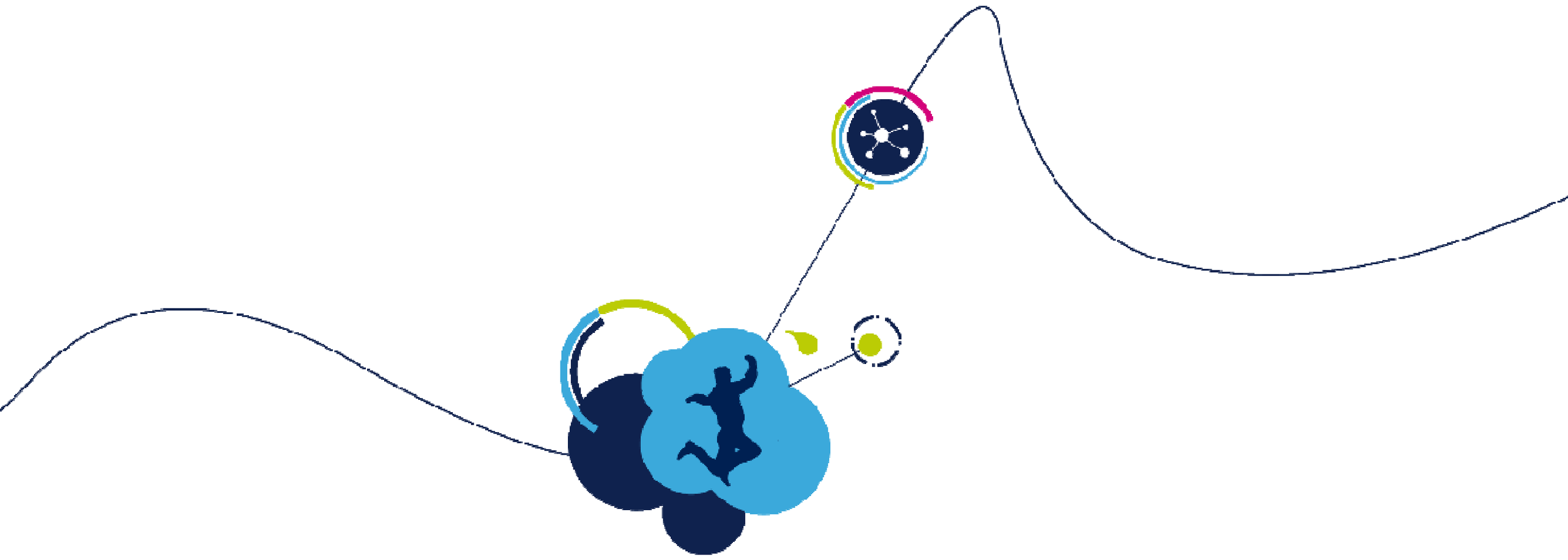
LONG Image, 1ms Exposure, Blur-Free, 72dB

MED & SHORT: 12ms Exposure, Flicker Free, 110dB





- Switching Between XHDR mode and Hybrid Mode done based on situation

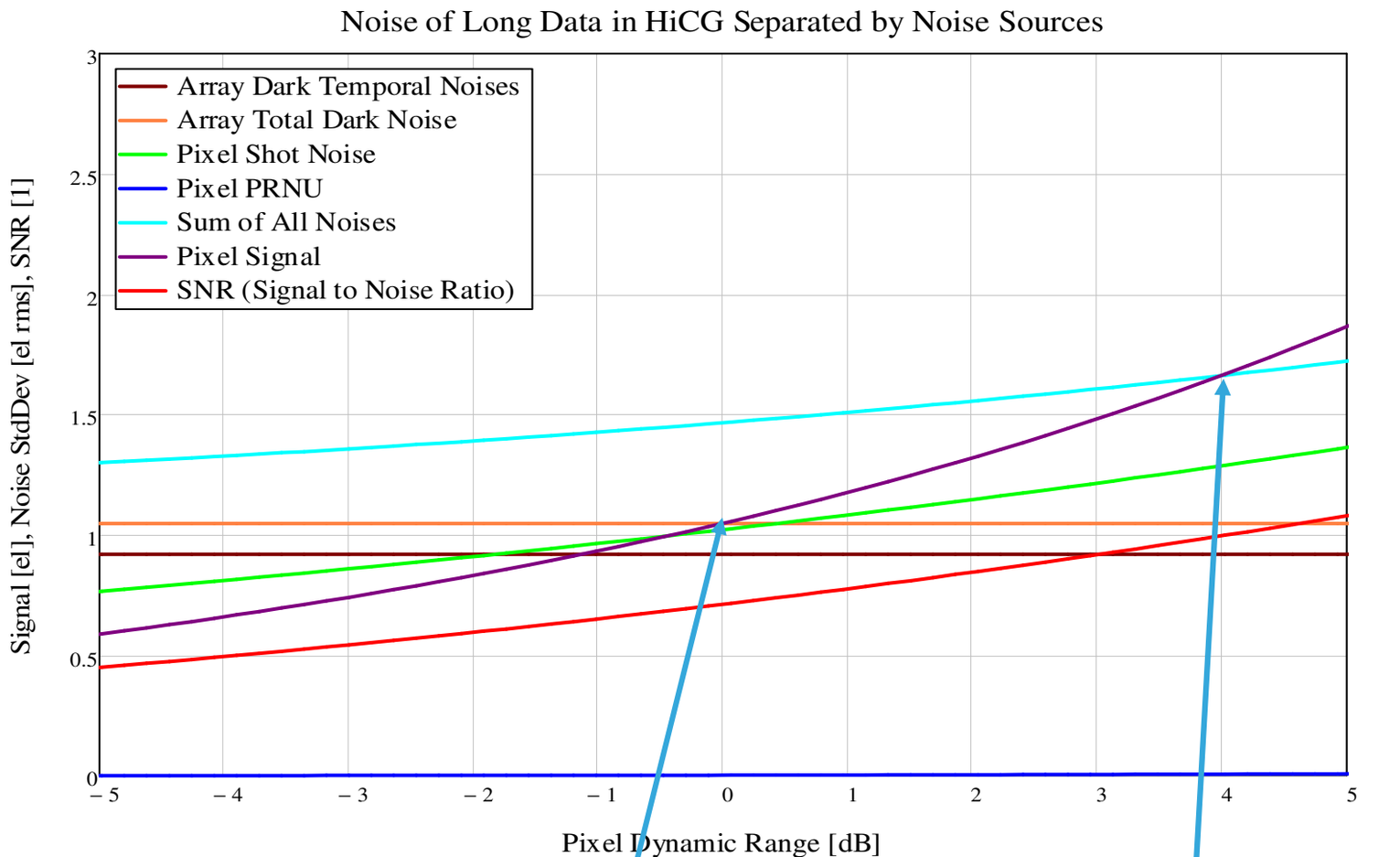


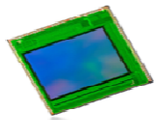
SNR, High Dynamic Range,

What does it tell me, and what not , what do I need?

Where Dynamic Range Starts

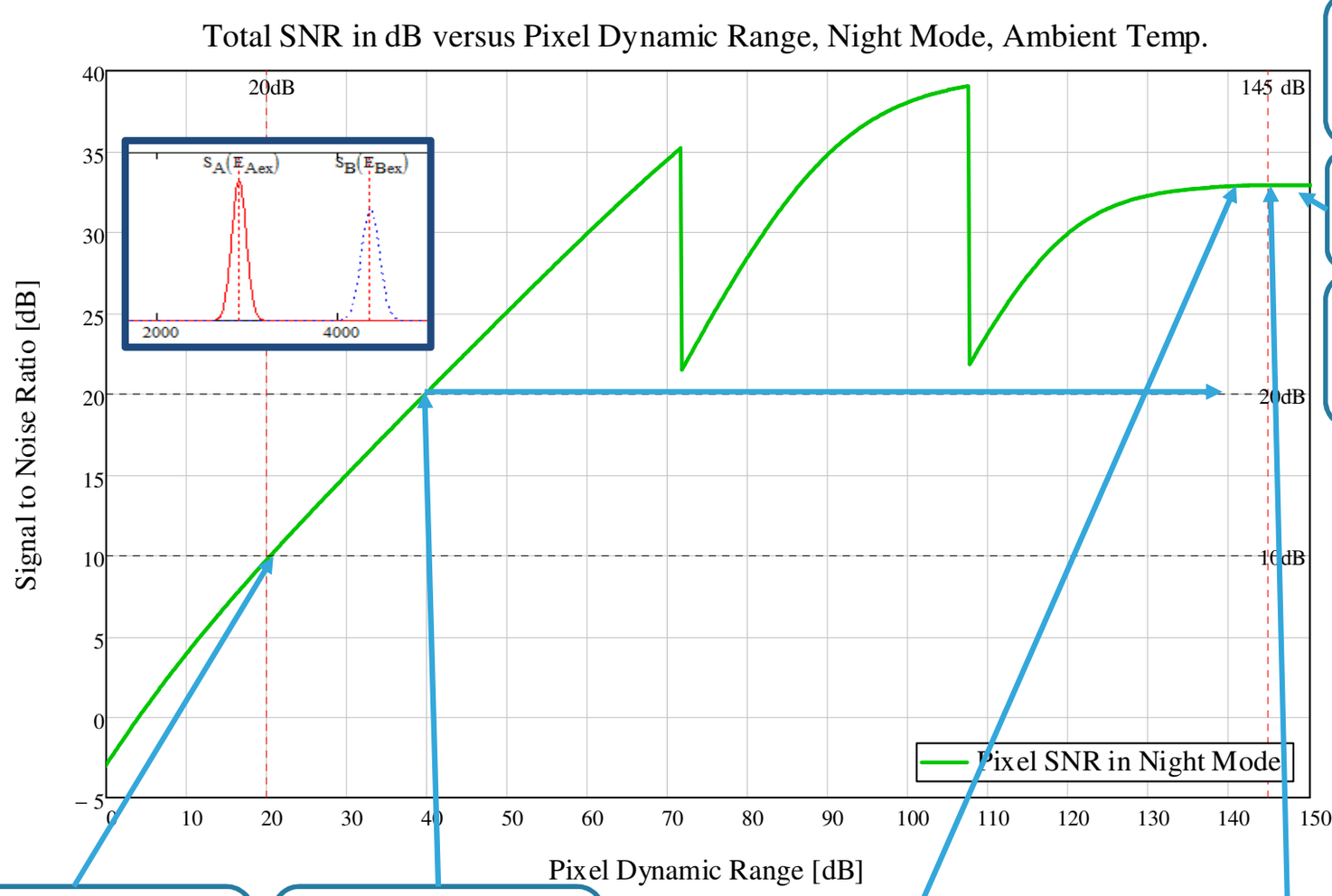
- Conditions:
  - D65, IRF, Green Pix, AG 1.0
- Camera: Night Mode, F1.6
  - 33ms-25ms-0.5ms,
- Signal = Dark Noise is the lowest Illumination that can be considered
- SNR = 1 at 4dB of Dynamic Range



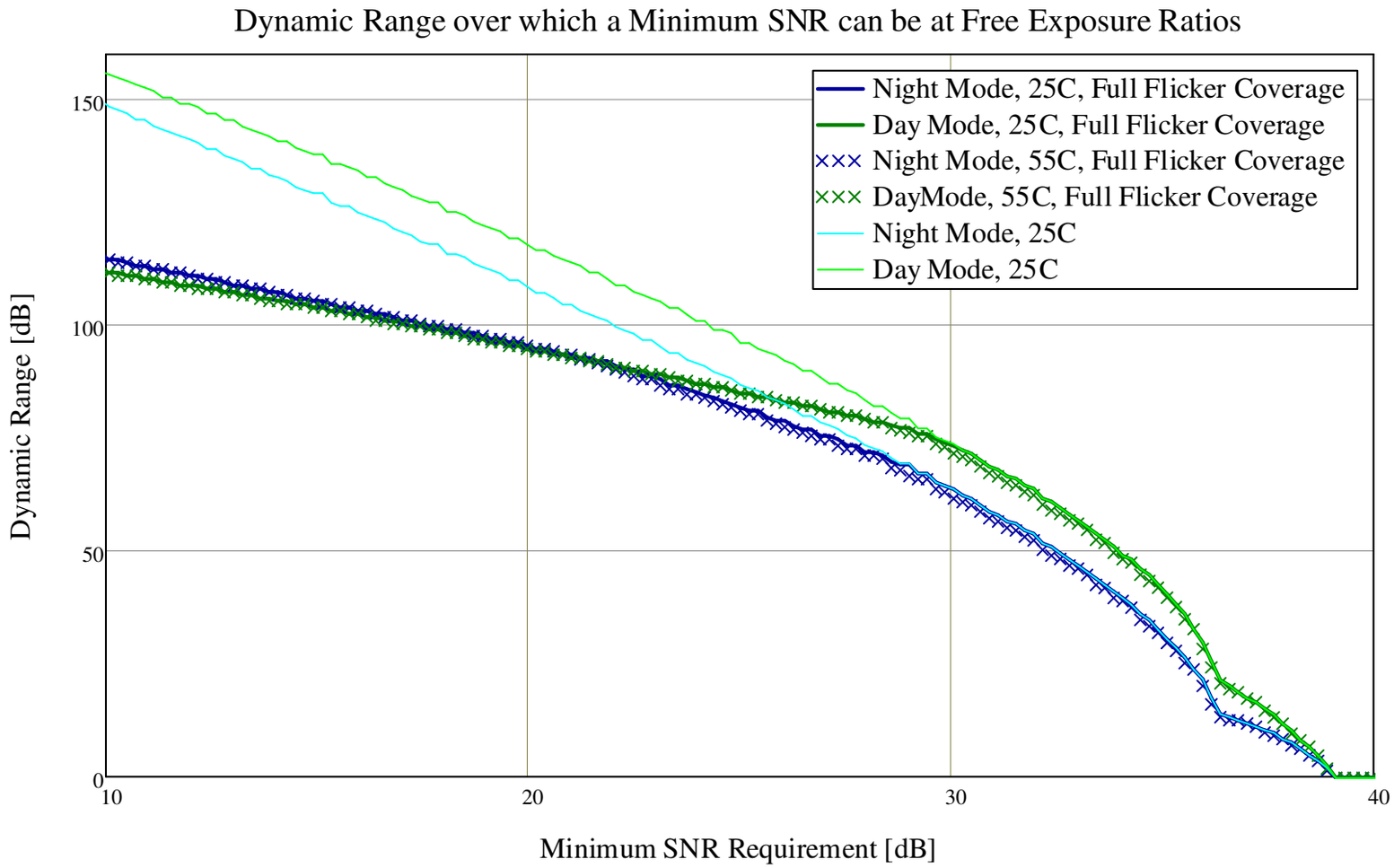


What the Dynamic Range Covers

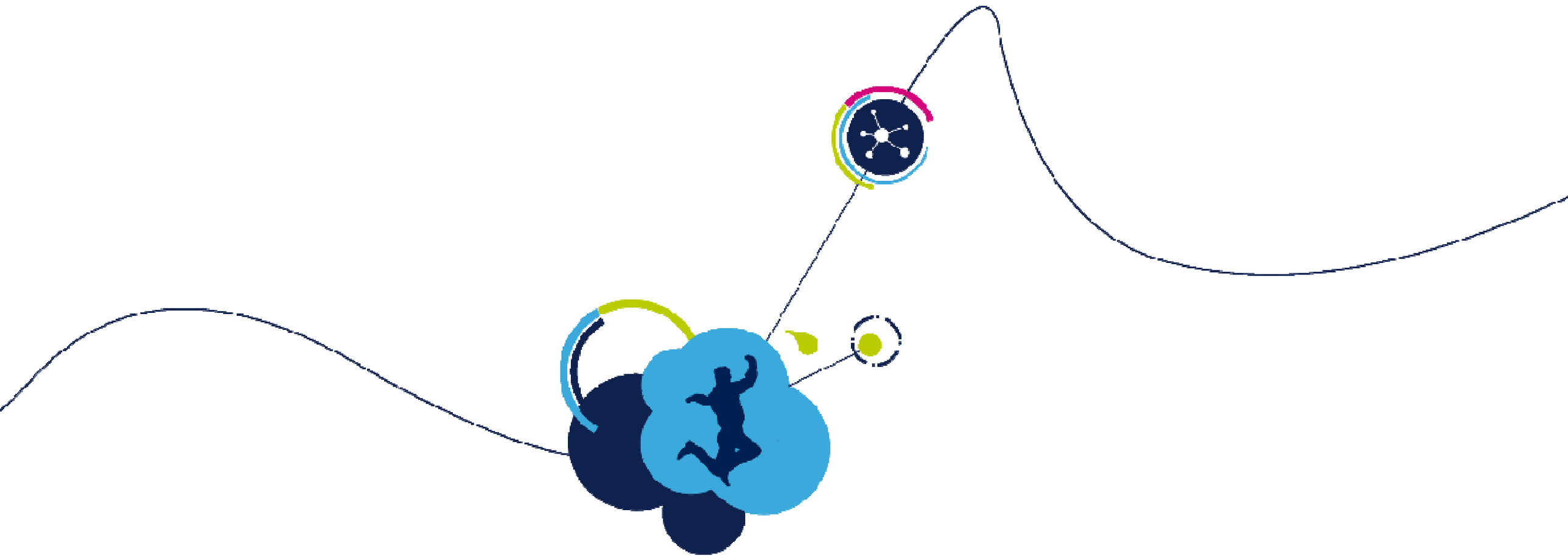
- Conditions:
  - D65, IRF, Green Pix, AG = 1.0
- Camera: Night Mode, F1.6
  - 33ms-25ms-0.5ms,
- Usable Dynamic Range counts up from a minimum SNR, e.g. 10dB, 20dB
  - depends on many factors:
  - Object to be detected, its size, texture, distance from camera, atmosphere
- SNR >21dB at any transition point
  - Always good image in mid tones
- 145dB Dynamic Range:
  - One frame captures all – exposure control



Dynamic Range versus Min. SNR



- Another way of looking at the sensor capabilities …
- Higher SNR, and Lower Dynamic Range with lower exposure ratios and vice versa



ISP and SNR

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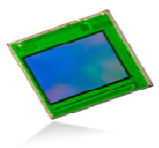
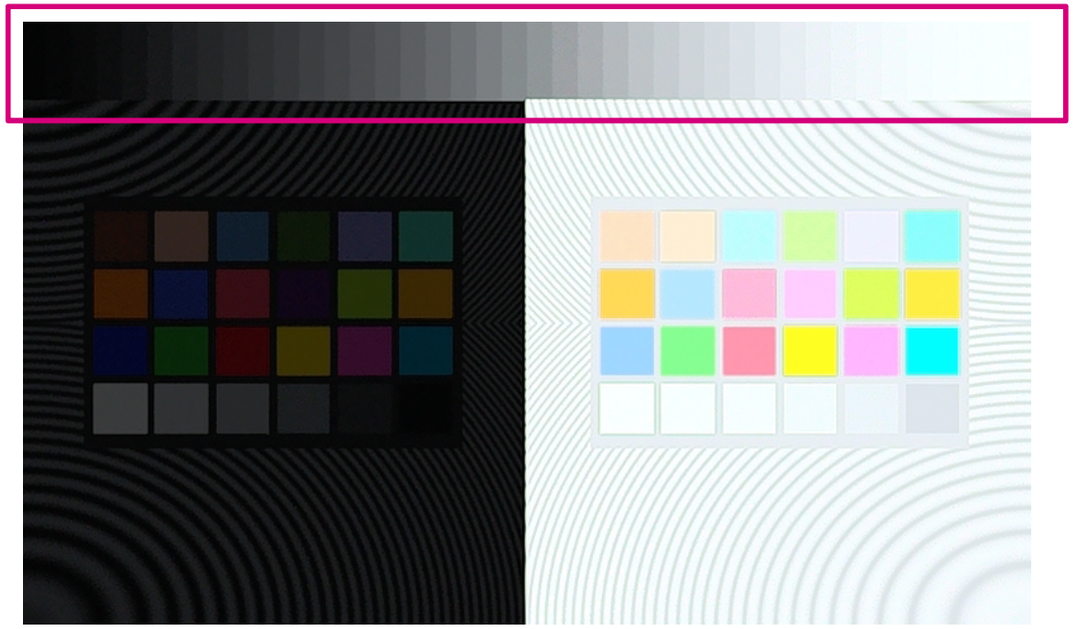
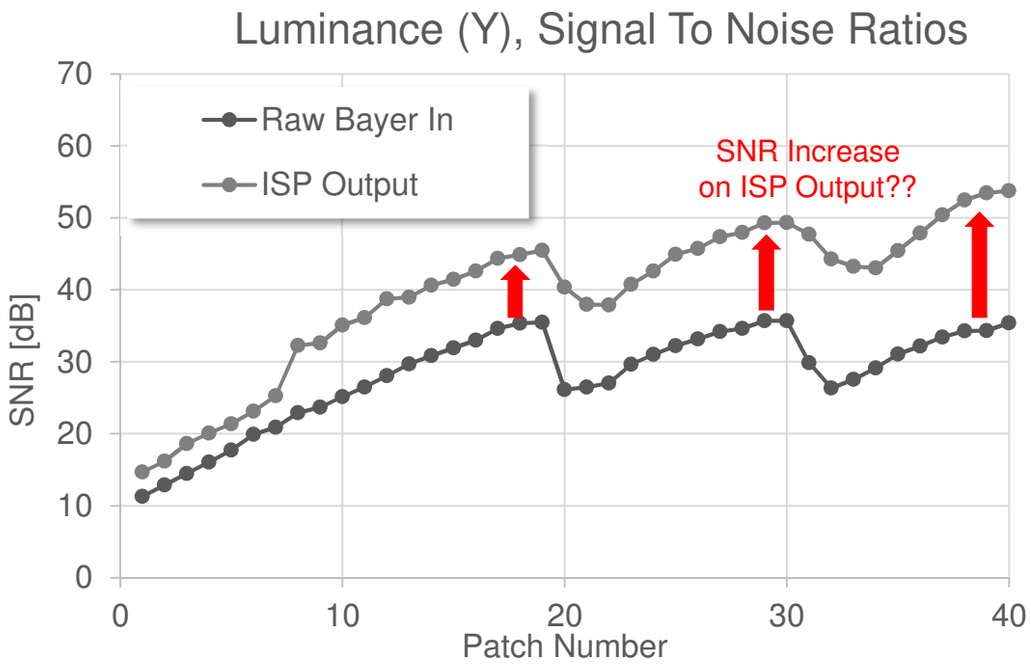


ISP Influence on SNR

- ISP
  - Transforms raw Bayer to Color RGB/YUV/Lab
  - Provides Best Possible Color Image
  - Impacts SNR, Dynamic Range
- Examples for Impacts
  - Subtractions (e.g. With Color Matrix) increase noise, reduce signal = reduces SNR
  - HDR Autoexposure must anticipate scene transitions
    - Keep DR headroom, expose to 20% of full Range
  - Pleasing images for human eye cut off low and high end of dynamic range

Synthetic Image to Study SNR through ISP

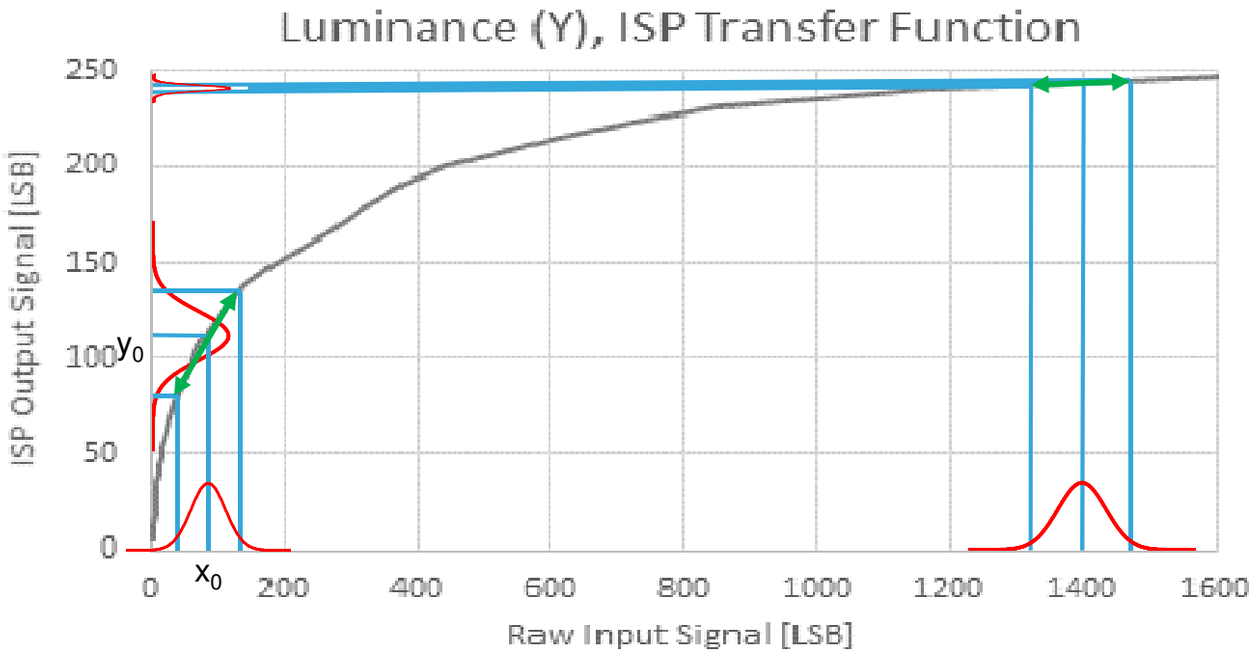


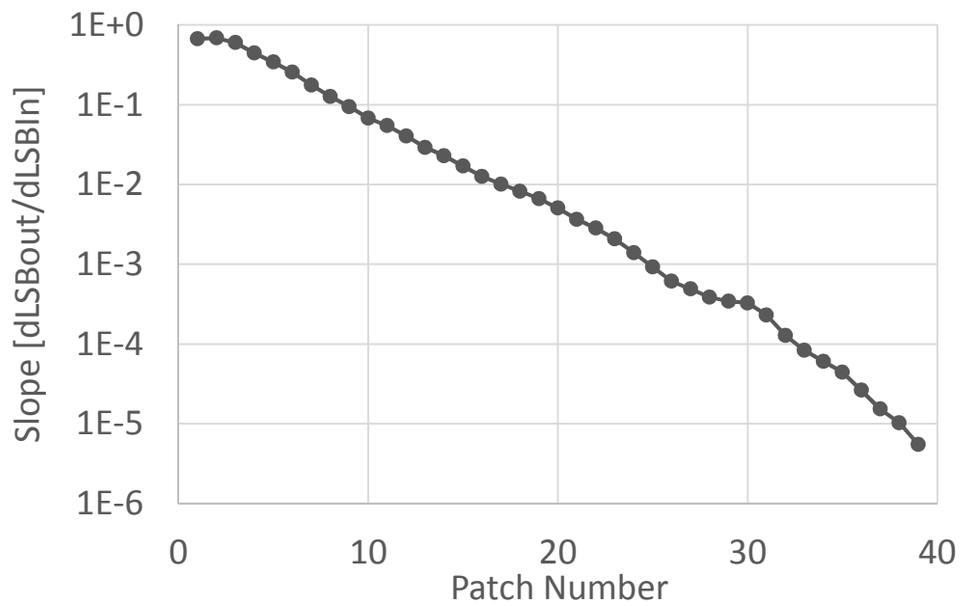


- Example Synthetic Image generated with Image Sensor model
- Processed with ISP
- 40 grey patches across 109dB Dynamic Range

- Is SNR really so much better?

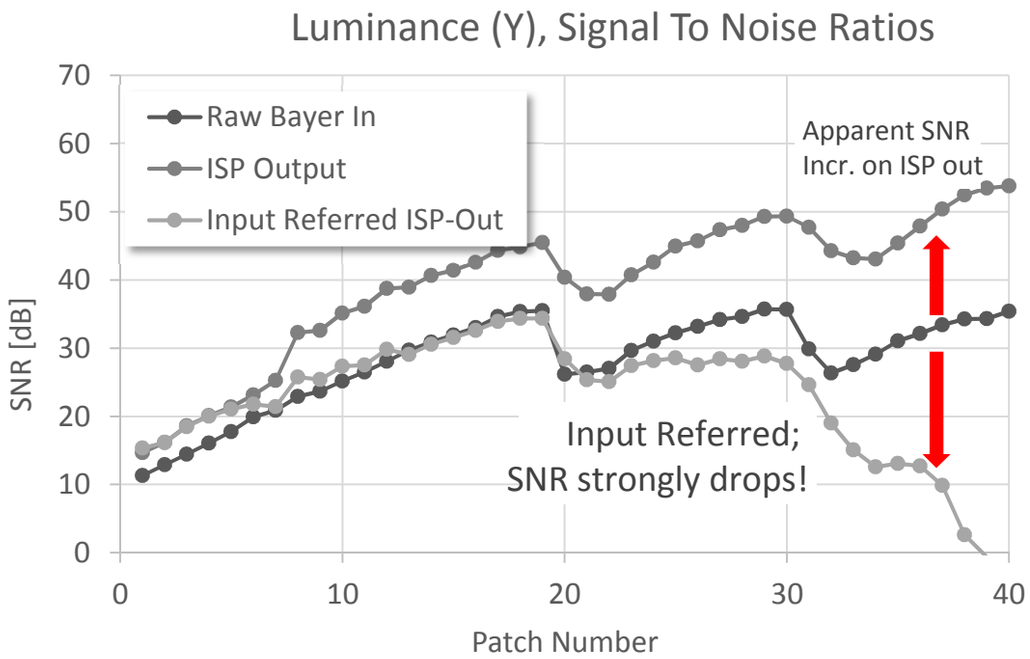
Example Simple Transfer Function

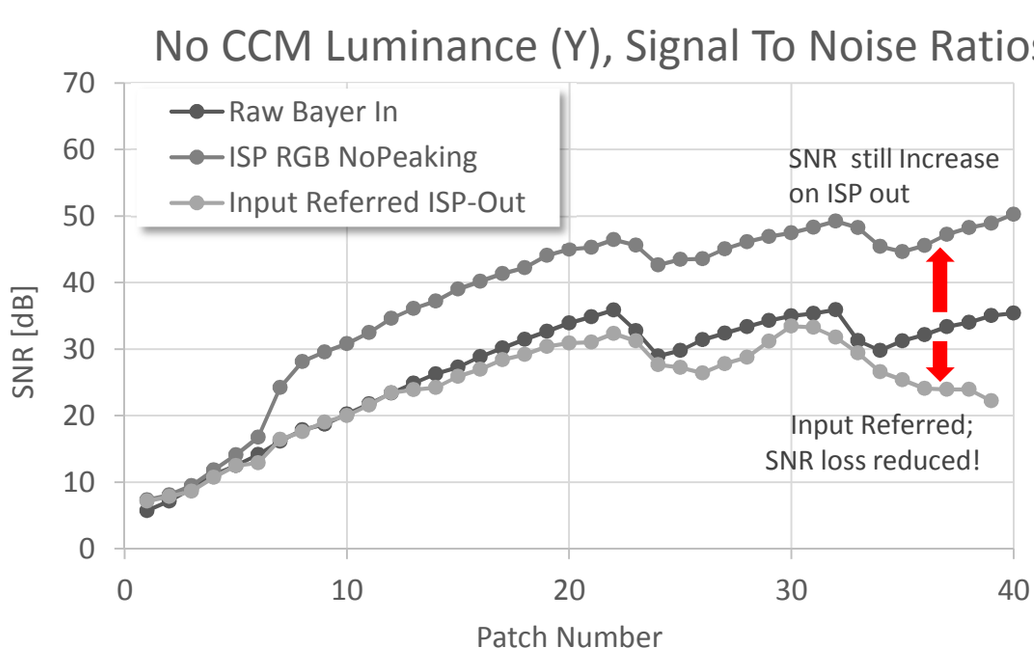




- To determine Contrast Detectibility after ISP,
  - the output noise needs to be referred back to the input
- y = f(x) contrast(y) = f'(x)*contrast(x)

Tuning Input Referred SNR

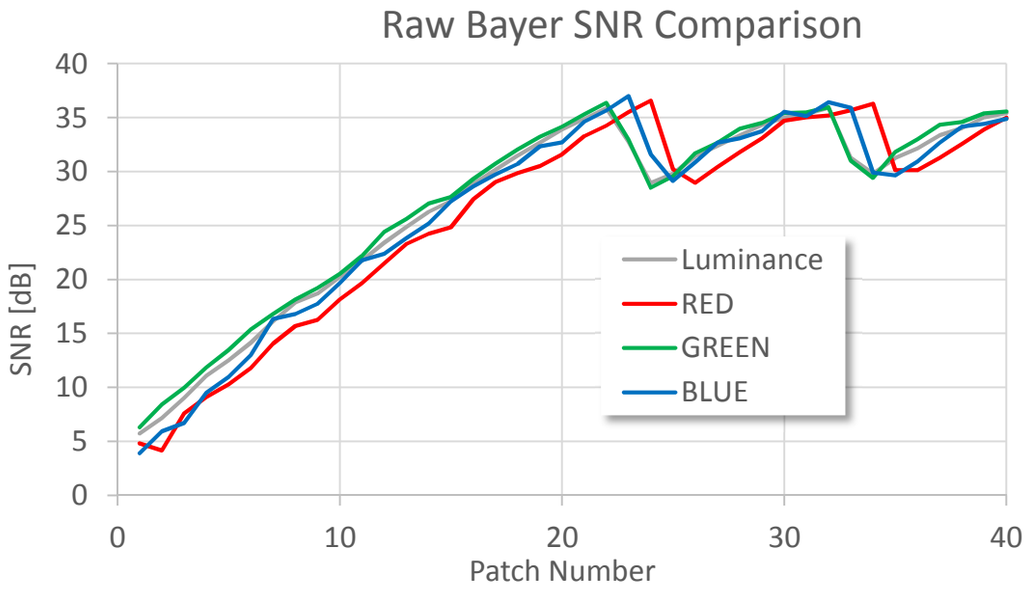


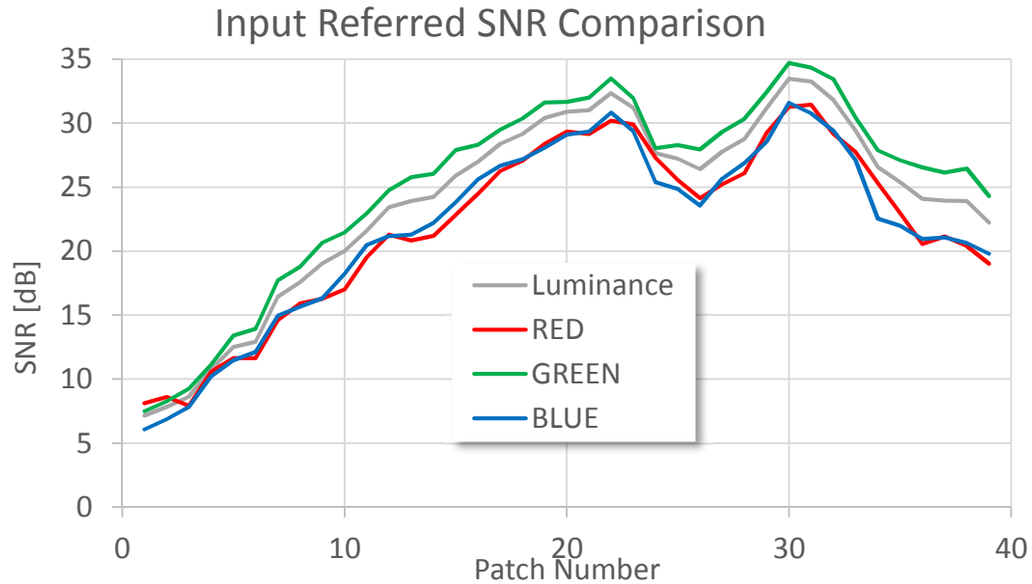


- Compare Output- vs Input Referred SNR
- Big loss due to … 8b Quantization

- Tune the Compression Curve to generate less SNR loss
- Tonemapping and Quantization have big impact on Input Referred SNR

SNR per Color Channel

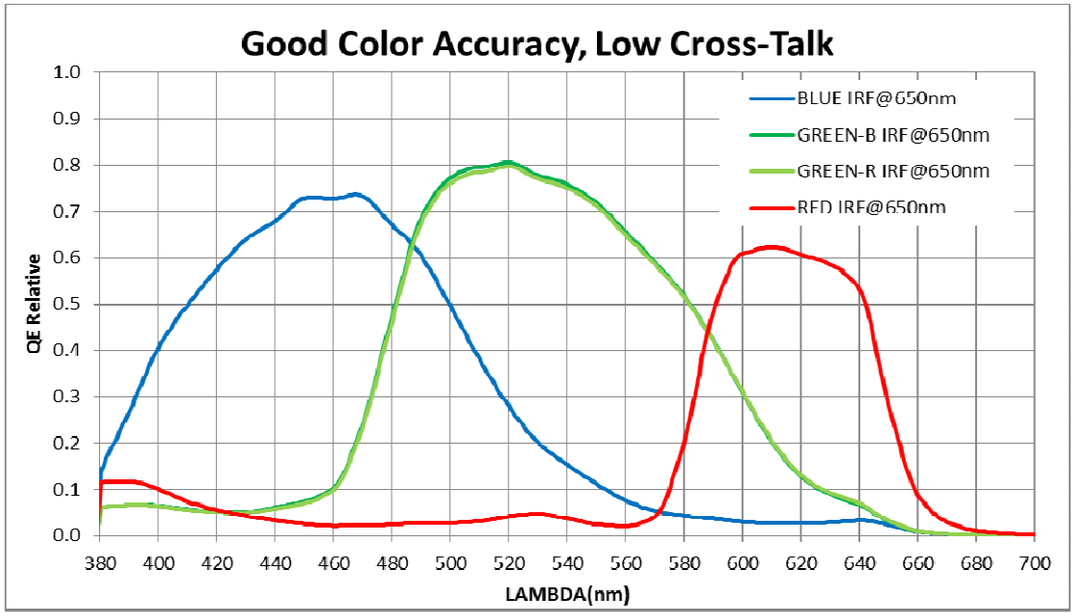




- Sensor Raw Bayer Information shows some SNR differences

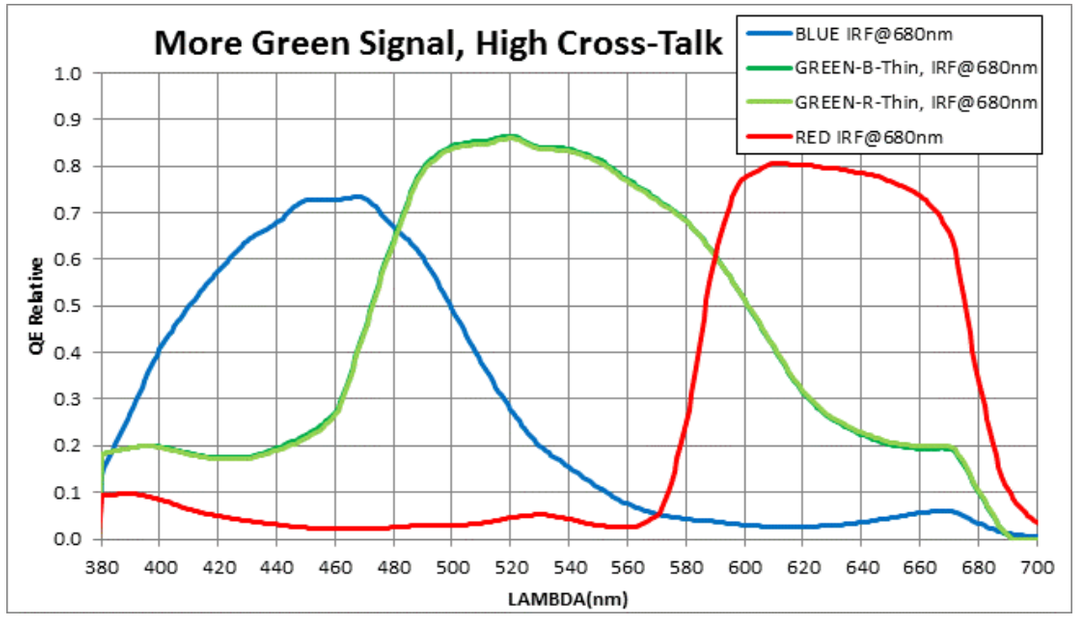
- SNR for G much better than for R and B

ISP Color Processing / Case Study



$$CCM_{LoXTalk} = \begin{pmatrix} 1.64 & -0.43 & -0.21 \\ -0.24 & 1.68 & -0.44 \\ 0.02 & -0.61 & 1.59 \end{pmatrix}$$

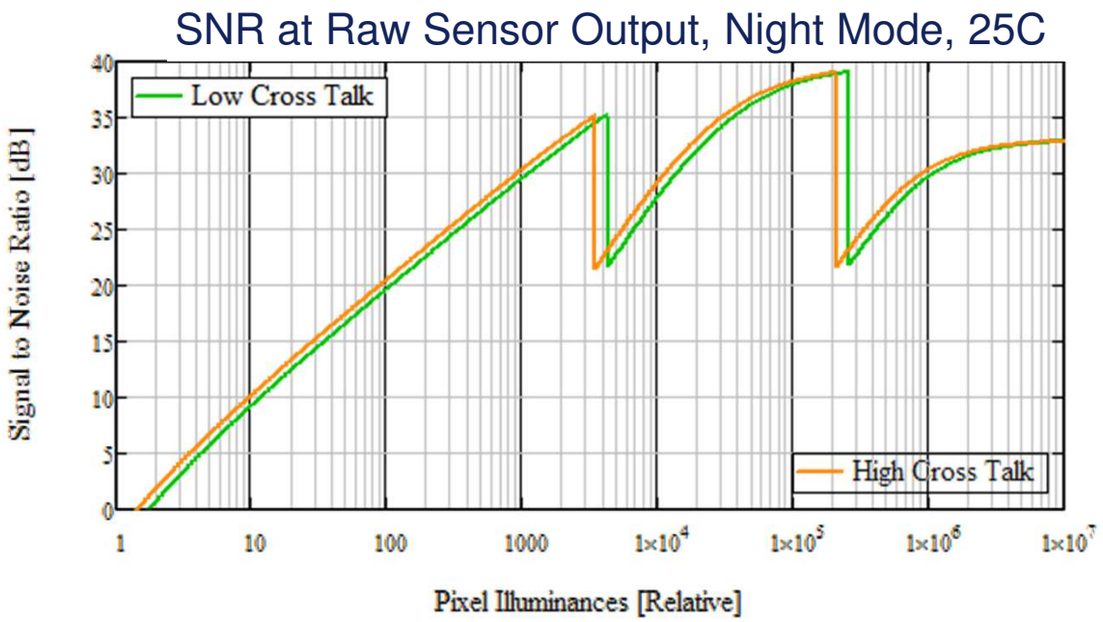
- Good Color separation, Low XTalk
- Reasonable Color Matrix

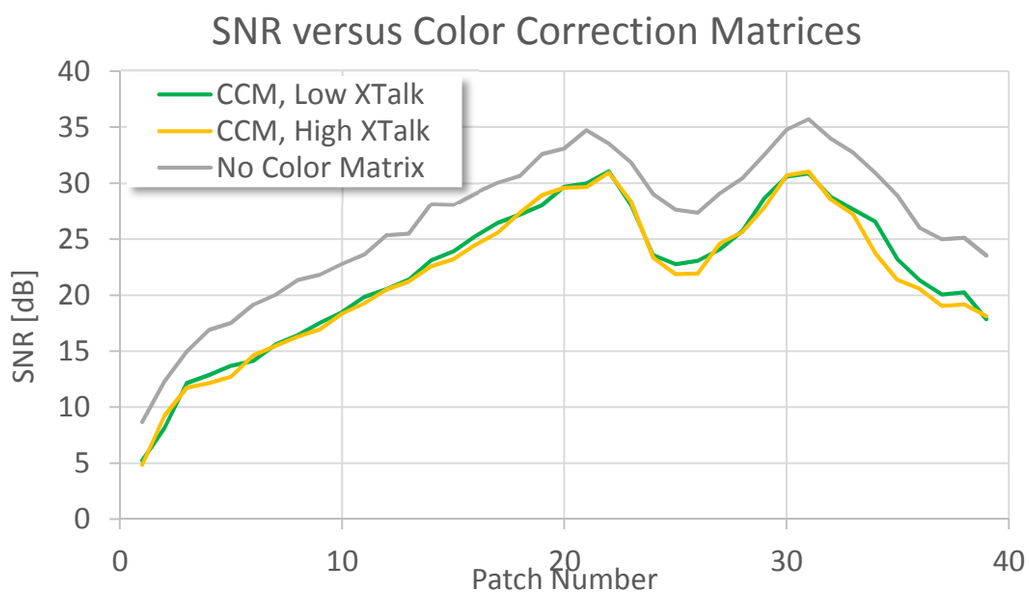


$$CCM_{HiXTalk} = \begin{pmatrix} 1.55 & -0.37 & -0.18 \\ -0.43 & 2.09 & -0.66 \\ 0.09 & -0.75 & 1.66 \end{pmatrix}$$

- More Signal, better Raw SNR, but be careful!
- More Crosstalk, bigger CCM Coefficients

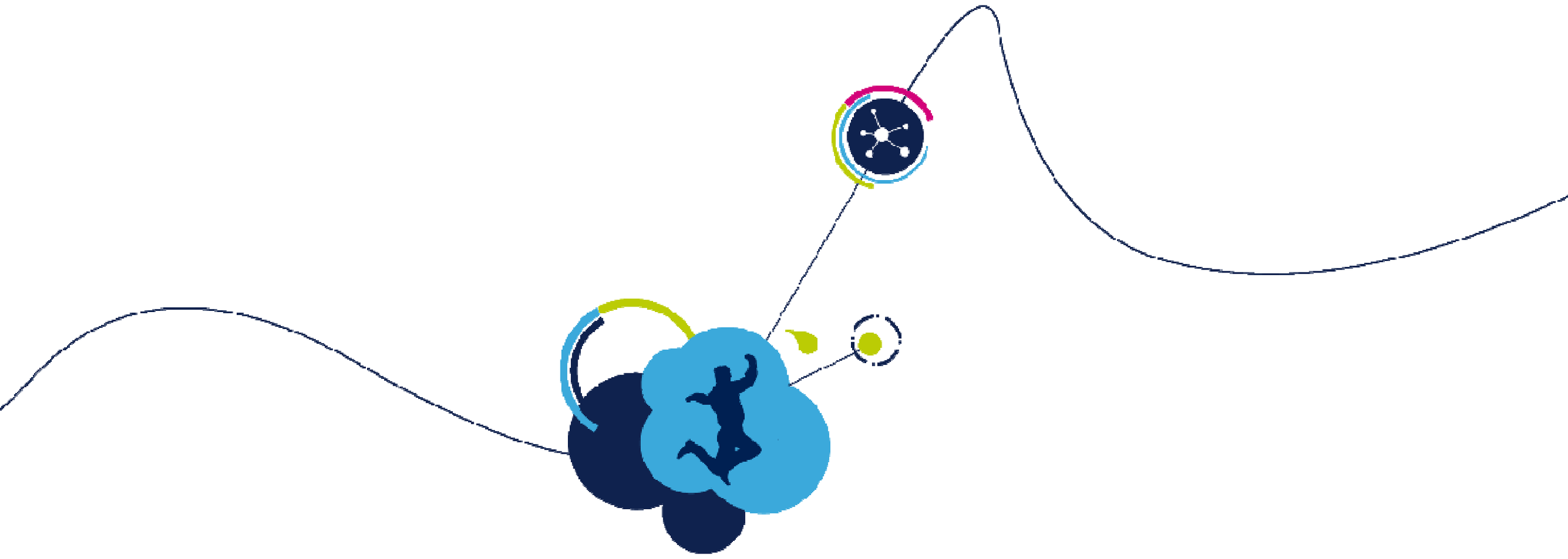
ISP Color Processing / SNR Comparison





- Noise Equivalent Pixel Illuminance better
  - Sensor seems 27% more sensitive!
- +1.3dB SNR gained at the raw sensor output

- After ISP, SNR drops through CCM
  - Drops more with High XTalk
- SNR Net effect negligible to negative
- Color Accuracy??



X-Dynamic Range Use Cases

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High Dynamic Range - Use Case

- R=80% directional
- 3.2*MLSB
- 120dB Scene DR

- 10LSB signal
- SNR=6dB
- 12dB Sensor DR

- 3.0LSB signal
- SNR = 0.3dB
- 4.5dB Sensor DR

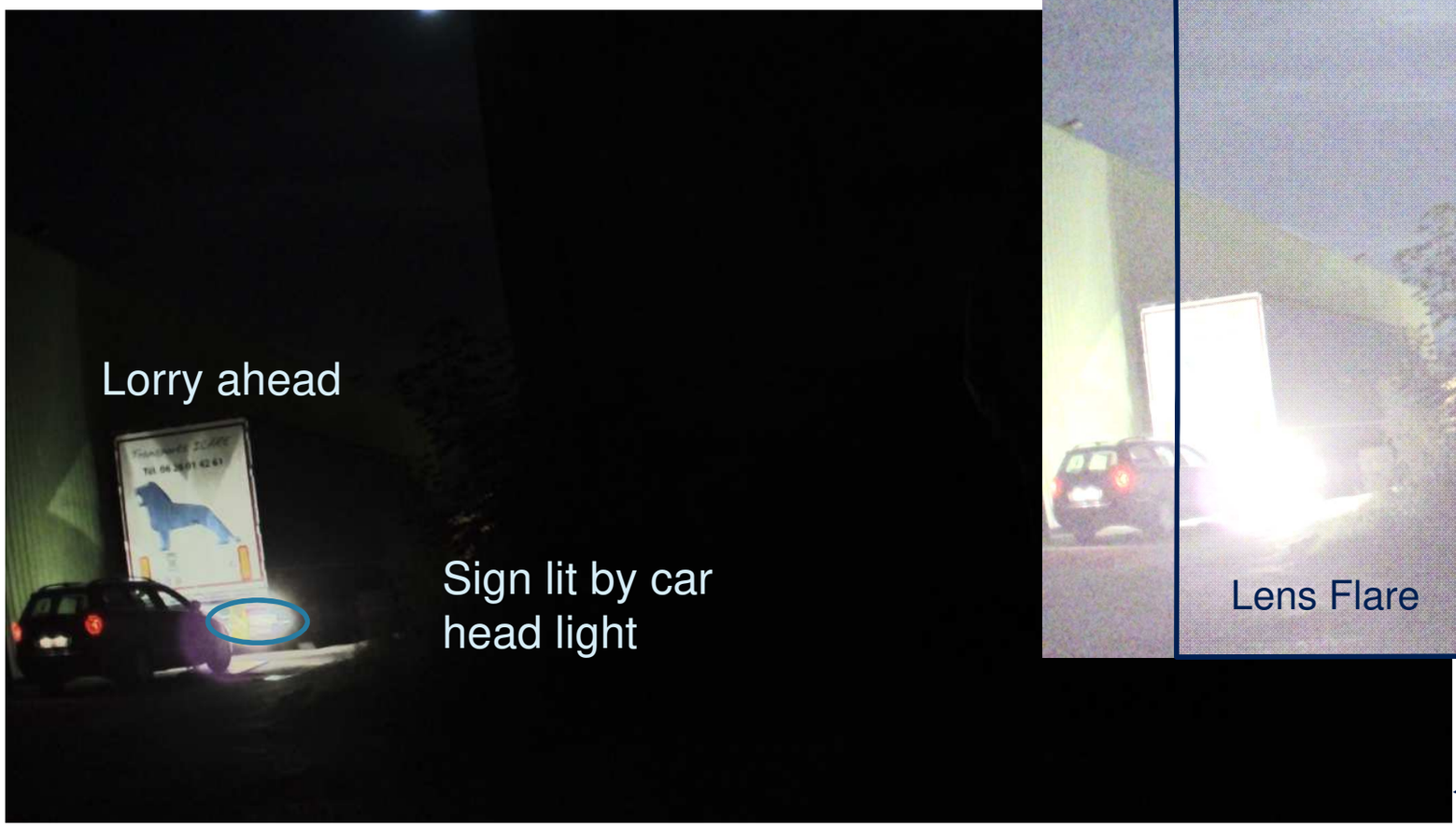
- VG6769 with 145dB, 32ms, Night Mode, HDR Lens, F1.6, 60deg FOV
- 125dB Sensor DR

High Dynamic Range – Comparison

	STM 145dB Imager	110dB Imager Simulation	94dB Imager Simulation
Use Case 1 / Bright Priority			
Use Case 1 / Dark Priority			
Conclusion:	All Highlight Information Preserved	Some Information Lost, Lower SNR	Much Information Lost

Xtreme Dynamic Range Use Case

Setup, Different Place:

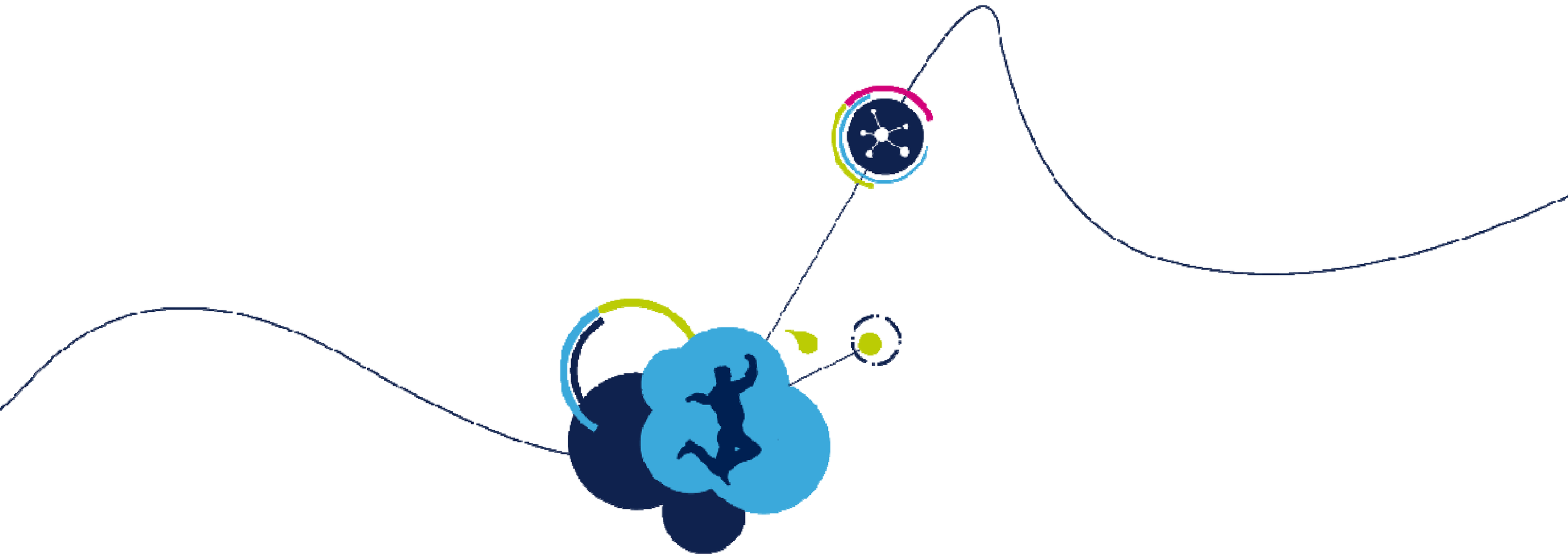


Xtreme Dynamic Range Use Case

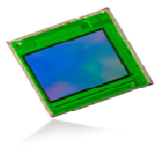
- 15 MLSB
- 127dB Scene DR

- 6.5LSB
- SNR = 3.6dB
- 10dB Sensor DR

- 137dB XDR: Only ST Imager can capture this @ 30Hz, Flicker-Free
- With XENON Headlights: Bright Part measured to be 3x Brighter – would still be OK for ST Imager



Conclusions



Conclusions

- Flicker Free and HDR are Mandatory for Automotive Imaging
- Knowing the Image Sensor properties is key to define the best System
  - Pixel Principle: Advantages, Limitations, HDR, Residual Flicker
  - Artefacts inherent to FF in general
  - Take into account by System Architects
- ST Hybrid mode provides blur free and flicker free simultaneously
- Real High Dyamic Range is Primordial
  - Good image needs SNR = 20dB ⇔ Already 40dB into Dynamic Range
  - ISP impacts SNR, DR
  - When the bright source is small: Even Today Lens Dynamic Range can be > 130dB!
  - DR > 130dB use cases measured: Sensor DR >> 120dB mandatory
- Only ST 145dB Imager provides headroom
  - Lower Sensor DR may pose safety risk

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Questions?