A 120dB dynamic range image sensor with single readout using in pixel HDR

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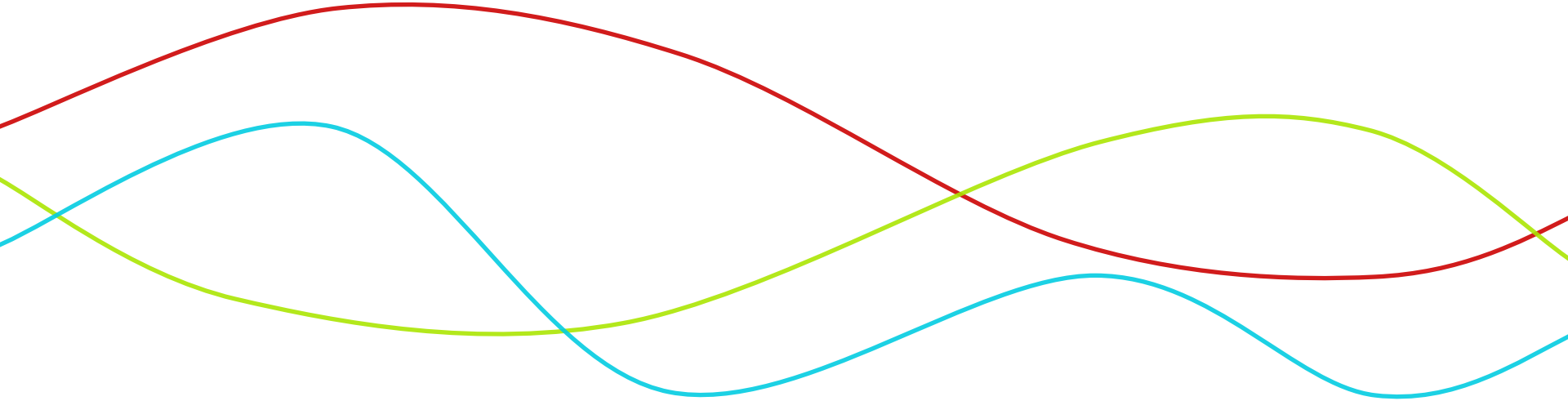


Grenoble HDR image

Outline

- Pyxalis
- Why HDR
- HDR solutions
- HDPYX sensor
- HDPYX experimental results
- Perspectives and summary
- Conclusion

Pyxalis in few words

- PYXALIS is a high-end CMOS Image Sensor supplier & Design house
- A few figures:
  - Founded in: 2010
  - Team: 20 people
  - Experience: >150 man-year experience in CMOS image sensors

- Located in **Moirans**, France , in the «Grenoble Imaging Vallée»:
  - 700sqm offices, state of the art design center, full EO characterization

Why HDR

- HDR stands for high dynamic range
- In many applications such as
  - scientific
  - space
  - consumer
  - security

- The dynamic of the scene is very variable or even unknown
- Handling of high dynamic range and change of scene lightning is necessary to get correct images
- Several solutions have been developed through years

Example

No HDR

HDR

HDR: several solutions

- Multiple integration times
  - Typically used in digital photography
  - In general at least 2 images are needed
  - Risk of motion blur due to the different exposure events
- Adjustment of the full well capacity during integration
  - The reset level is modulated during integration time
  - The Qsat is modulated by the reset level
- Spatial variation of the exposure
  - Pixel sensitivity is patterned in the matrix (density filters, fill factor…)
  - Pattern (like a Bayer color filter) of different filtering factors
  - Reconstruction

HDR: several solutions

- Logarithmic sensor
  - In CMOS using a MOS in subthreshold
  - Subject to MOS subthreshold parameters dispersion
- Multiple readout gain
  - Several analog chains using different gains

HDR: several solutions

HDR solution	Multiple integration times	Well adjustment	Spatial variation of exposure	Logarithmic	Multiple readout gain
DR					
high luminance	↗	↗	↗	↗	↗
low luminance	same	same	same	worse	↗
Linearity	Yes	No	Yes	No	Yes
CDS	Yes	No	Yes	No	Yes
SNR	+	-	-	--	+
Complexity					
Pixel	Low-medium	Low	Low	Med	Low
Readout	Low	Low	High	Low	High
Main drawbacks	Several asynchroneous large memory needs	Dispersion of the reset voltage can create artefact in reconstruction, if furtive event occurs during reduced well the signal is partially lost	Need for reconstruciton and interpolation, spatial resolution is reduced	Low sensitivity at low light levels	

In one frame only

One output chain

HDPYX sensor

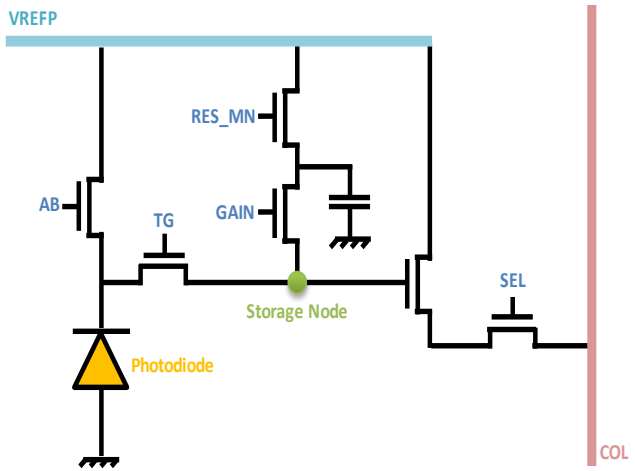
HDPYX: HDR sensor

- Multiple gain readout
  - With only one output conversion chain
  - In pixel gain
  - Automatically switching gain during readout
  - Integrated hdr reconstruction up to 92dB dynamic
- Multiple integration time
  - Interleaved line integration time in one frame
  - Programmable up to 128x ratio
  - Integrated hdr reconstruction up to 114 dB dynamic
- Combination of multiple gain and multiple integration time
  - Up to 120 dB dynamic range

HDPYX: specification

Resolution	3 MP (2800 x 1088)
Pixel type	10µm 6T pixel
Dynamic range	Up to 120dB linear dynamic range
Read noise	2.5e- read noise
ADC	14bits column ADC
Frame rate	45 FPS @ Full-resolution
Shutter mode	Rolling, snapshot, pipeline, global shutter low noise
Data output	Configurable LVDS or CMOS, Up to 20 bits data
Readout modes	windowing, subsampling, ROI, flip, mirror, acquisition sequence programming
Black reference for dark – FPN reduction	64 lines 64 columns of shielded pixels for dark
Digital functions	CFPN correction, HDR reconstruction, HDR Tint interpolation

HDPYX: pixel

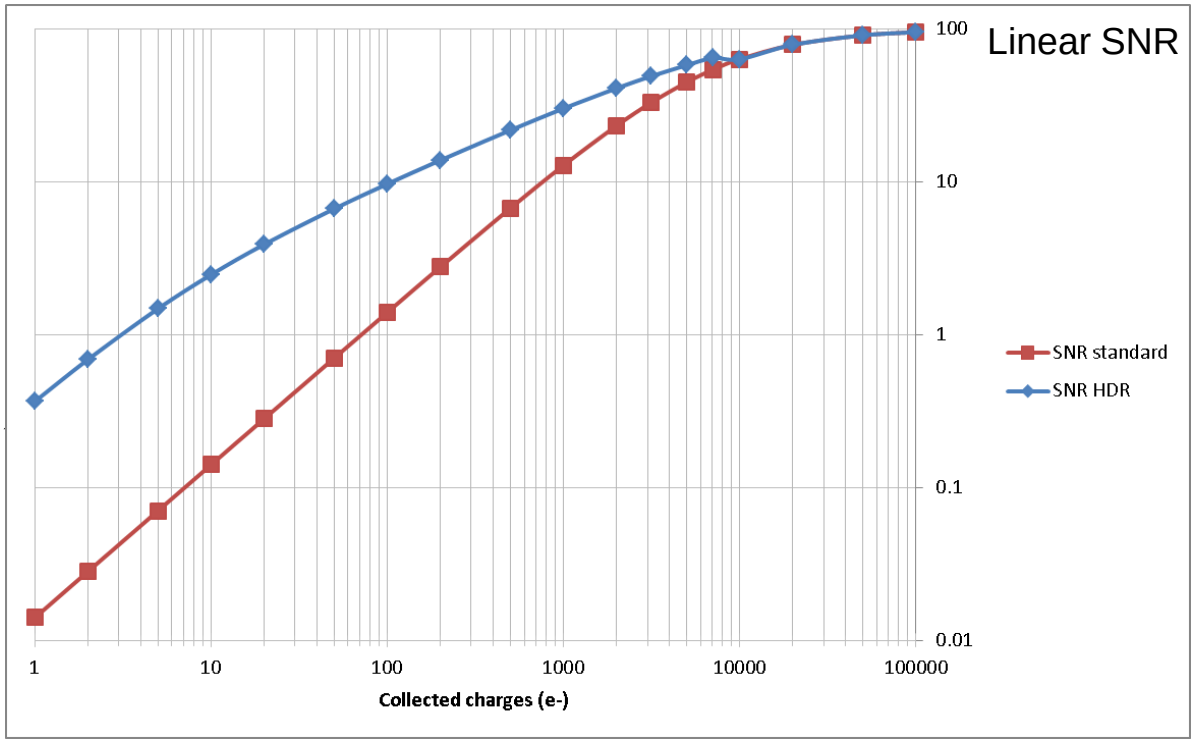


- 6T pixel based on a classical 5T pixel
- Global or rolling shutter
- 2 gains in pixel

HDPYX: ADC

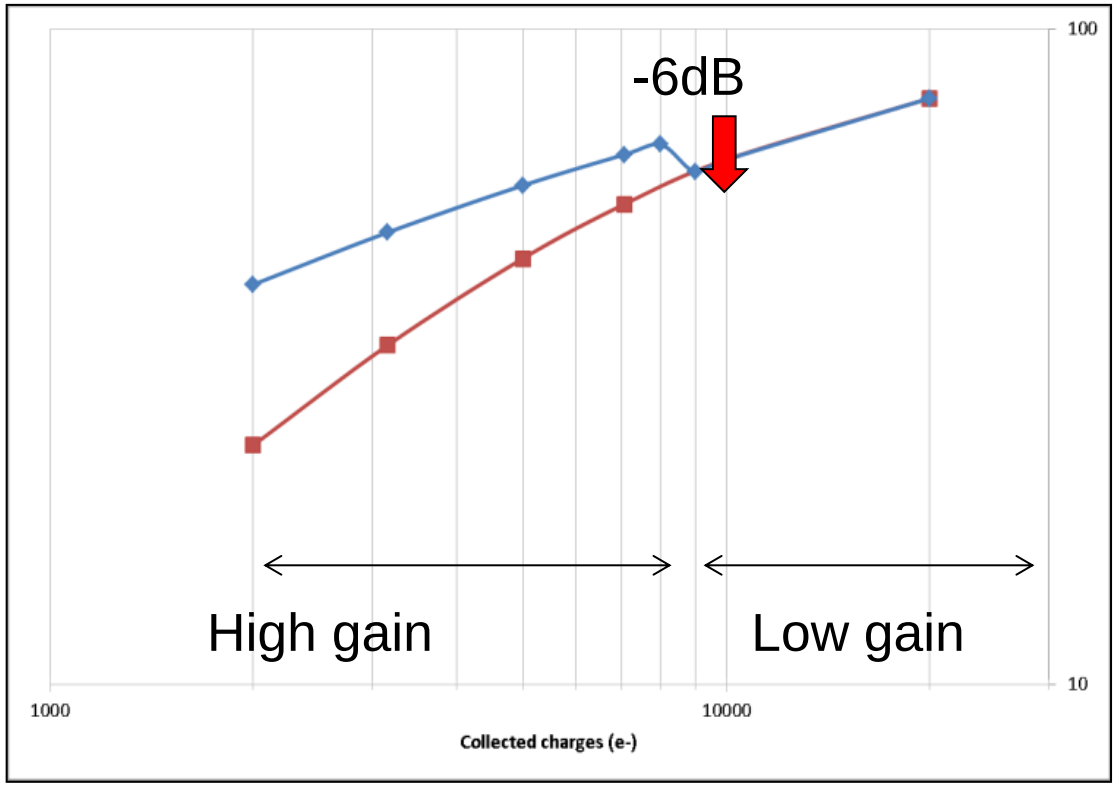
- Dedicated HDR ramp ADC
- Using a programmable threshold detector in the ADC the pixel gain is selected
  - If the signal in high CVF is not saturated we keep it
  - If the signal in high CVF is close to saturation, switch the gain and re-sample
- In high CVF (low signal level, low read noise), CDS is performed while on low CVF (high signal level, higher read noise) UDS is performed
  - When UDS is performed the signal level is high enough
  - The noise is dominated by shot noise

HDPYX: SNR in dual gain



- To achieve the same Qsat with only one gain the noise is increased in the low illumination
- Using a dual gain in pixel, SNR is improved in the lowest part of the dynamic by reduction of the noise for low illumination

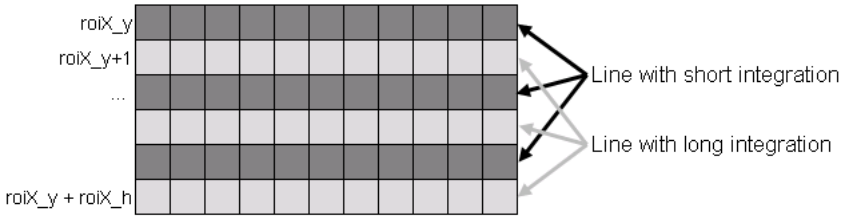
HDPYX: SNR in dual gain



- SNR is improved in the lowest part of the dynamic
- There is a small fall down of the SNR at the transition between the 2 gains
- It is needed to place this transition where the shot noise is high enough

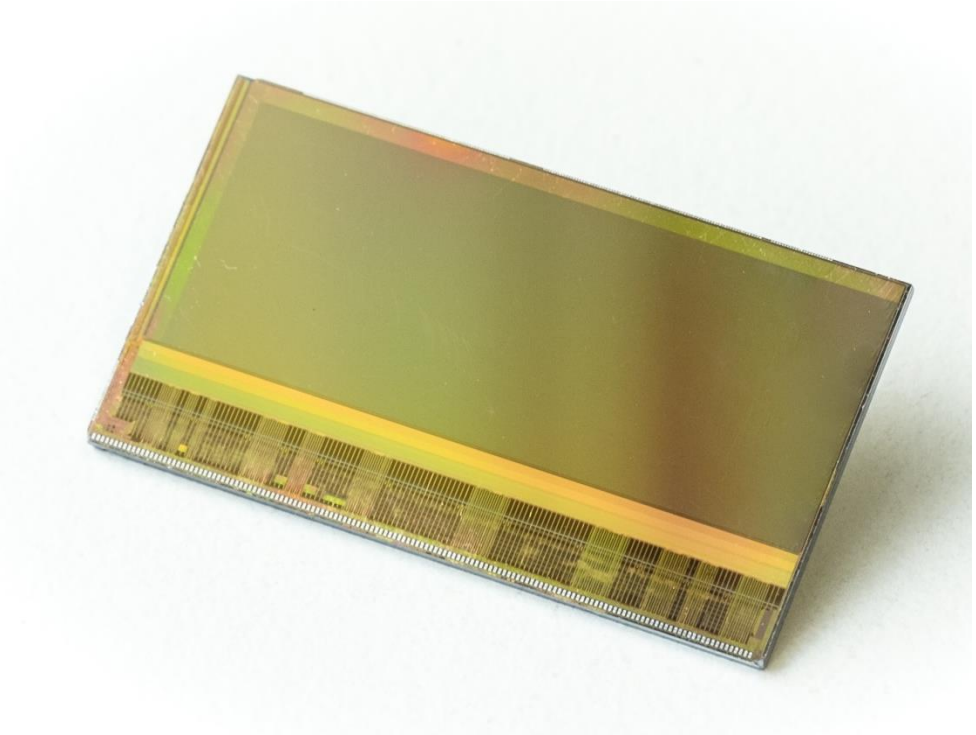
HDPYX: dual integration time

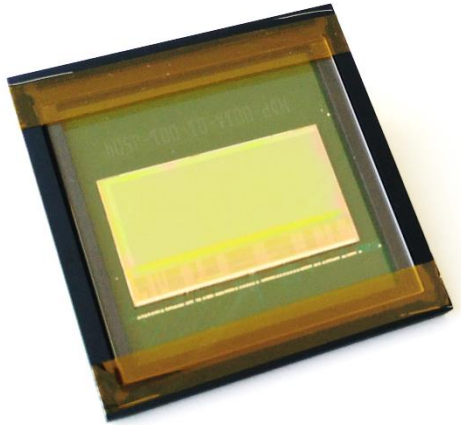
- The pixel lines integrate for long or short time



- It is possible to program 2 ROI shifted from 1 line to alternate between long and short time on the same line
- Up to 128x between long and short integration time
- Only one readout is performed

HDPYX: silicon

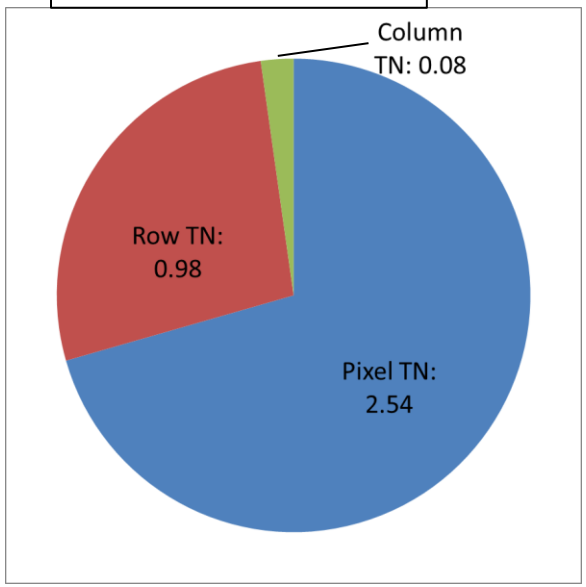


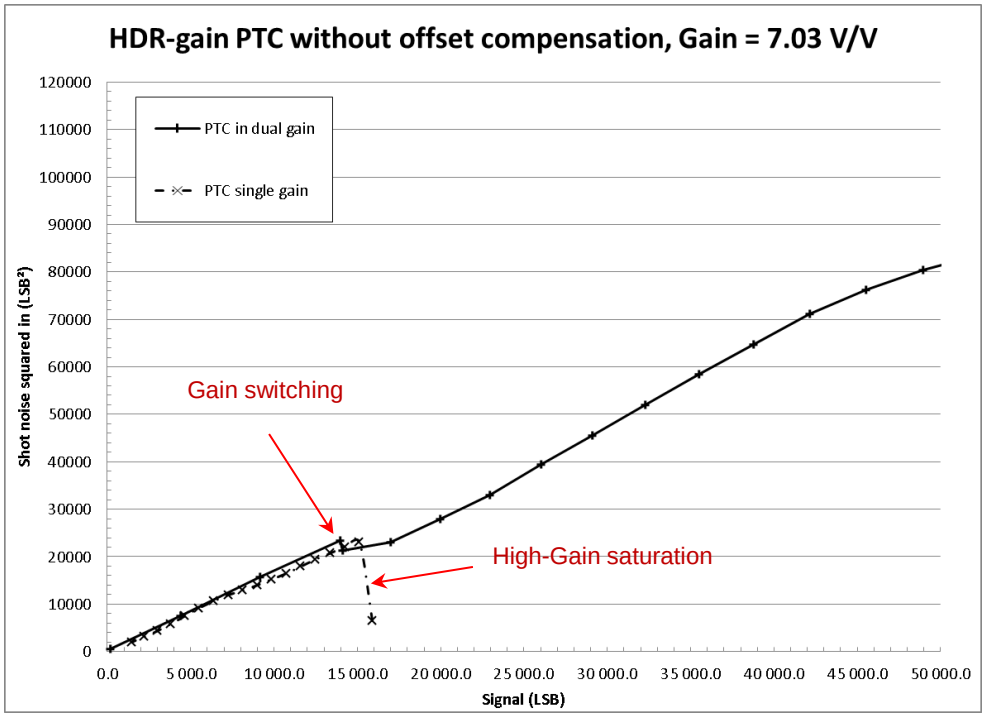


HDPYX: experimental results

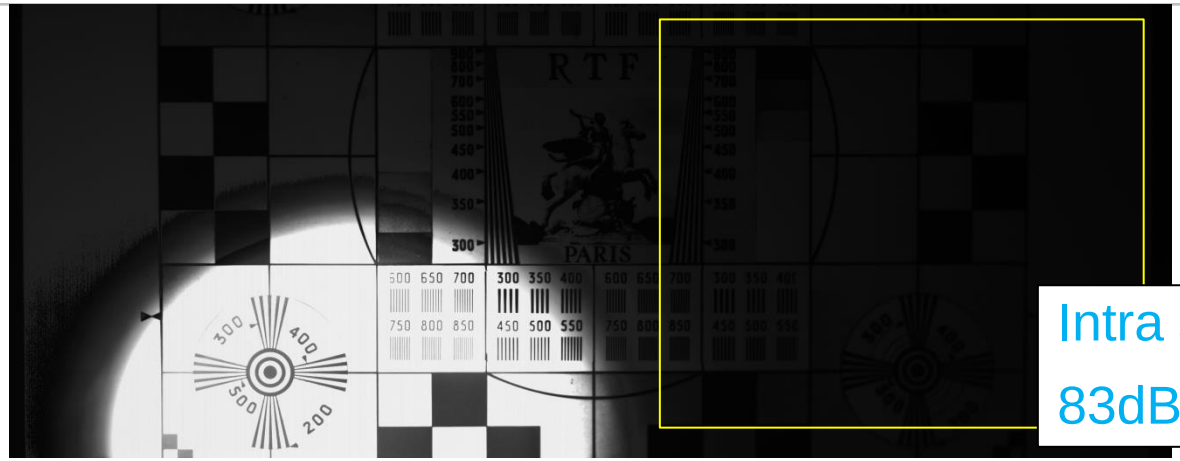
- Measured pixel temporal noise of 2,5e- rms in high gain
- In pixel gain of 7 between high and low CVF

Total TN:2.7e-





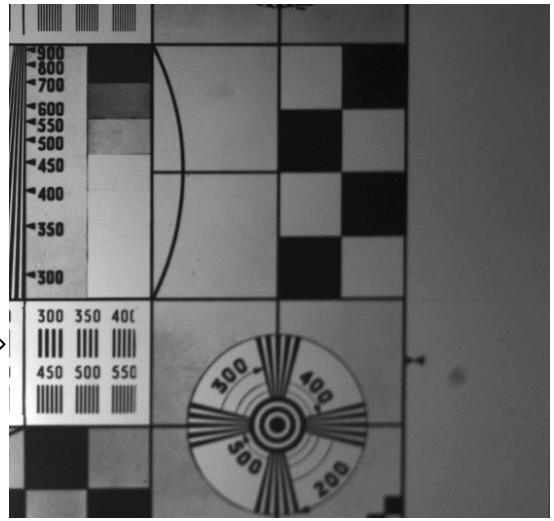
HDPYX: HDR image in gain only

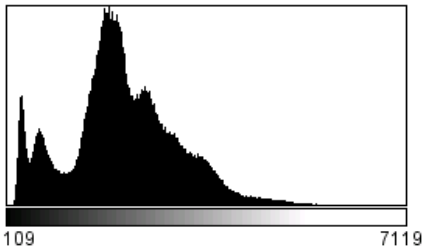


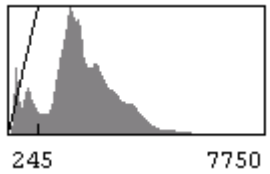
Intra scene:

83dB dynamic coded on 16 bit

Contrast expansion to show the details







HDPYX: perspectives and summary

- Summary
  - 2,5e- rms pixel read noise / 70ke- full well lin
  - In pixel gain of 7 (so 89dB dynamic range in dual gain)
  - Up to 120 dB using HDR combined solutions
  - Linear solution (compatible with color, and digital processing)

- Future versions are planned
  - Backside illuminated version
  - High thickness epi for low energy X-Rays sensitivity

Thanks for your attention!