Diagnostic Imaging System for MAGIS-100

Understanding Camera DAQ Performance

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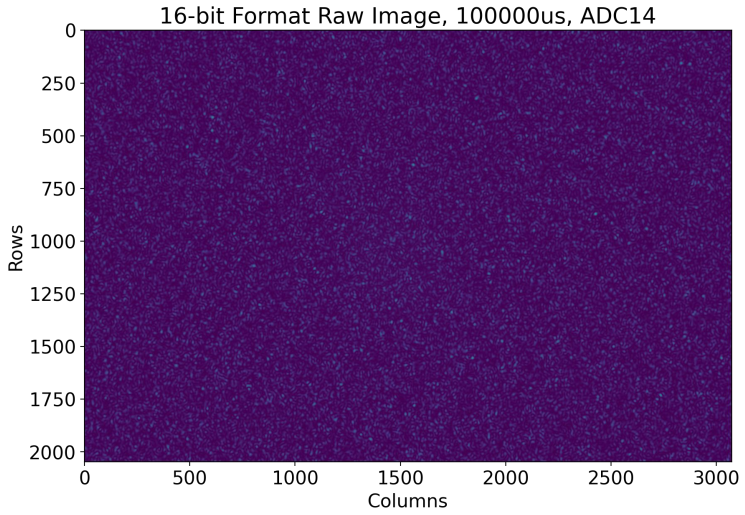
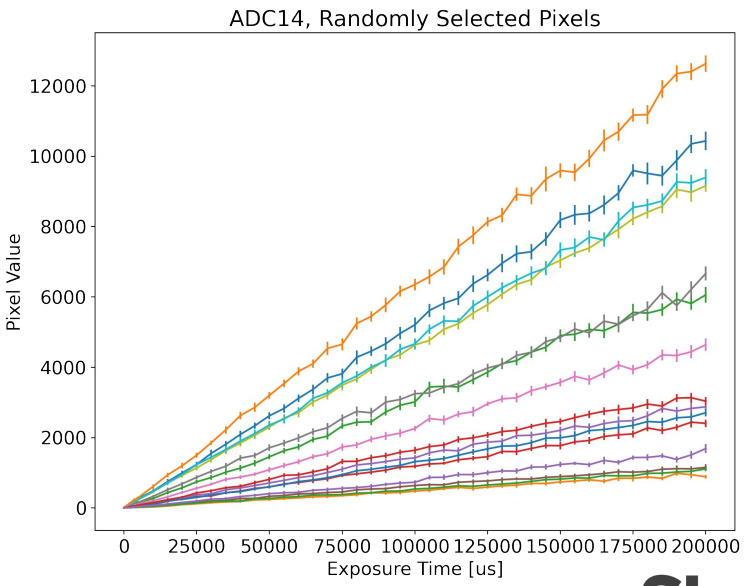
Agenda

Understanding and analyzing DAQ of DIS alignment cameras

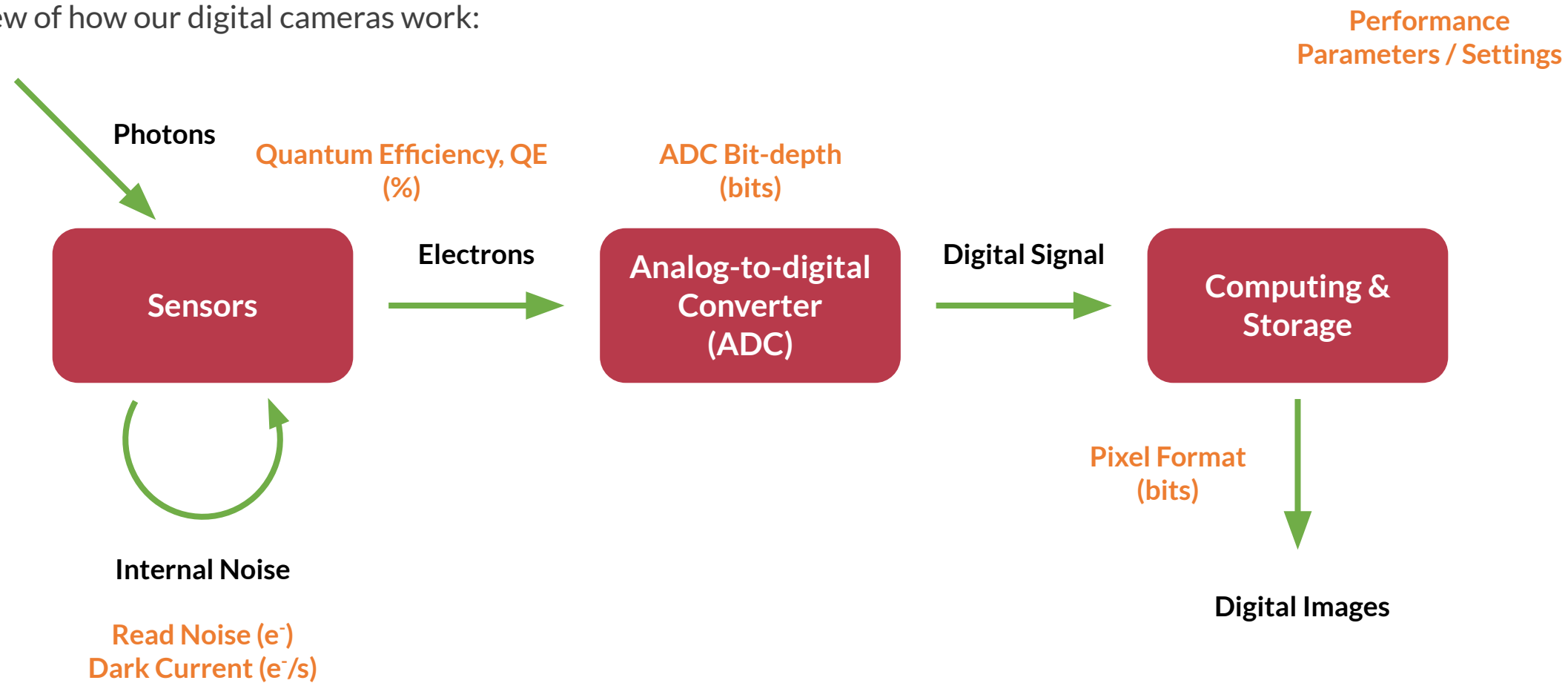
- ADC bit-depth & pixel format
- Response & noise studies
  - Read noise & dark current
  - Signal Response
  - Photon shot noise
- Rolling shutter & global reset behavior
  - Analysis in progress, might need more data





From Photons to Digital Images

Review of how our digital cameras work:



(Could we add these to gradoptics simulations?)

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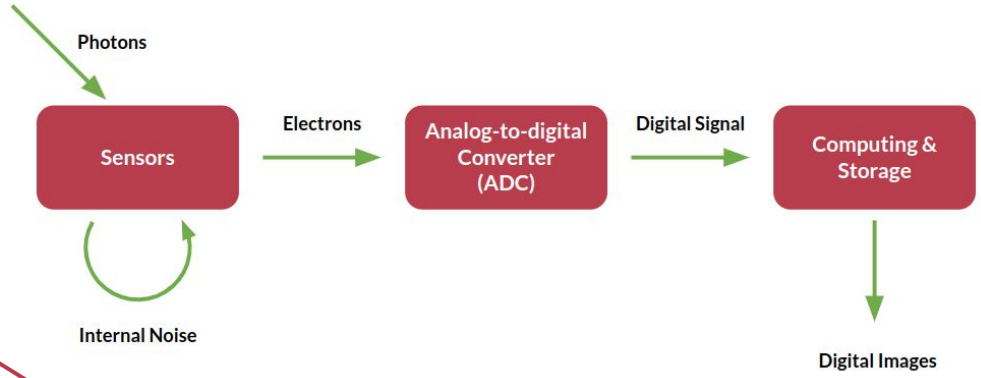
Parameters & Settings Related to DAQ

Review of relevant parameters / settings:

- Quantum Efficiency, QE (%)
  - % of photon → electron conversion
- Read noise (e^-) (also called "temporal dark noise")
  - Error in measuring analog electrical signal
- Dark-current (e^- / s) (also called "dark shot noise")
  - Thermal electrons in sensors
- Saturation capacity (e^-) (also called "full well depth")
  - Max. analog signal stored at each pixel
- ADC bit-depth (bits)
  - Resolution in converted digital values, ADU
- Pixel format (bits)
  - Format in final digital images
  - Higher than ADC bit-depth doesn't add information



Determined by camera hardware

Tune-able by software

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DIS Alignment Camera

Specific values for DIS Alignment camera: BFS-PGE-63S4M-C, Sony IMX 178, Mono (link)

- Quantum Efficiency, QE = 77.07% @ 530nm
- Read noise = 2.55e^-
- Dark-current = not quoted
- Saturation capacity = 14177e^-
- ADC bit-depth = 10/12/14 bits
- Pixel format = 8/12/16/24 bits

For example:

- Consider **16-bit format** images taken under **ADC14**
  - Pixel value range = [0, 2^{16} - 1] = [0, 65535]
  - 2^{14} = 16384 possible ADU's ⇒ pixel value in units of $2^{(16-14)}$ = 4
  - Each ADU corresponds to 14177e^- / 16384 = 0.865e^- or 1.12 signal photons (dividing by QE)
  - **Pixel value of 4 = 0.865e^- = 1.12 signal photons**

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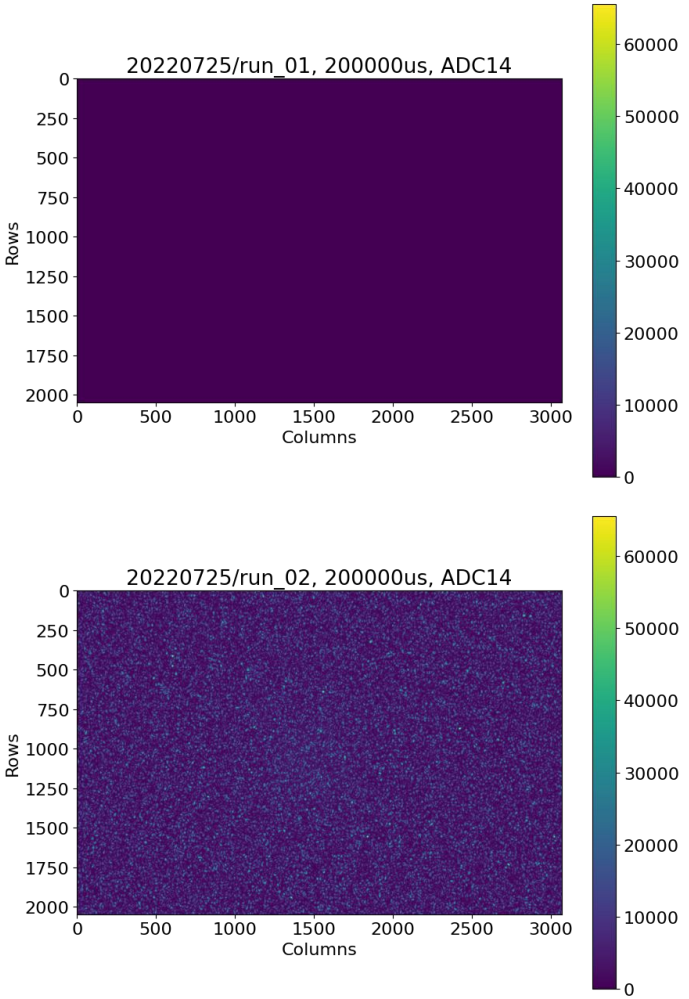
Lab Images Taken

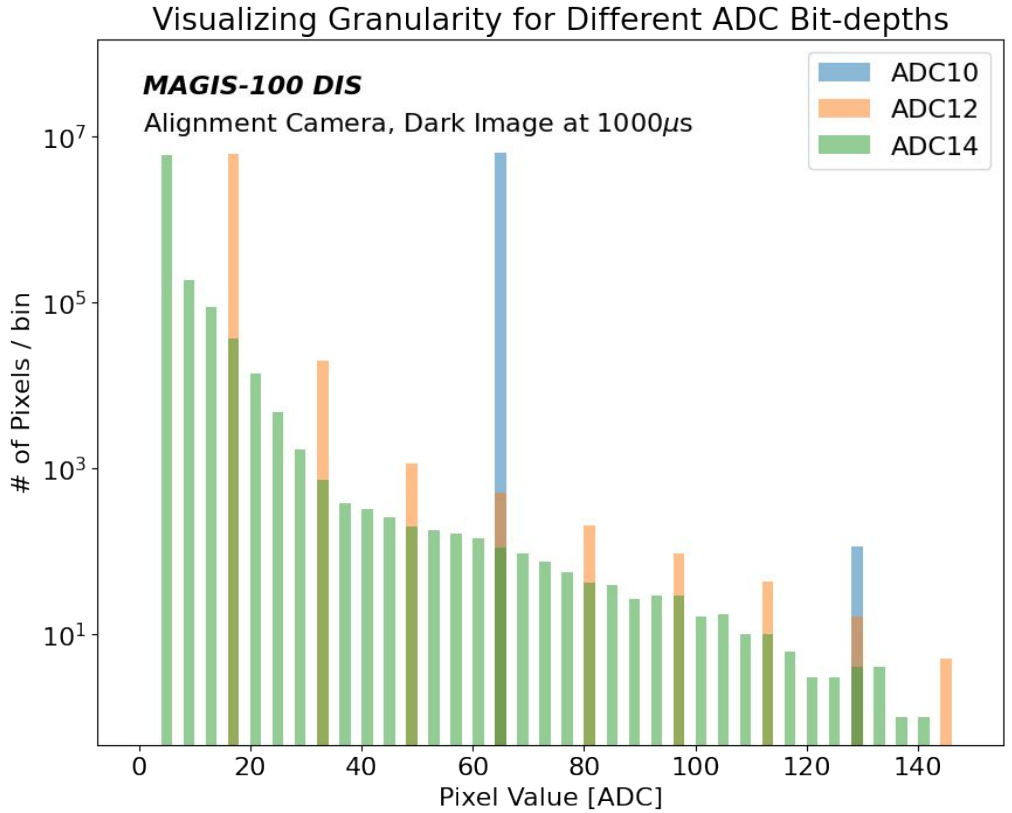
All data stored in: `/sdf/group/magis/data_storage/DIS/lab/2022_some_date/run_some_number/`

- All images in 16-bit pixel format
- ADC10/12/14
- Exposure time ranging **from 25µs to 200ms**
- 20 images per setting (to boost statistics and estimate error)
- `20220725/run_01/`
  - "Dark" images for read noise studies (lid on & dark room)
- `20220725/run_02/`
  - Images of "flat-field" (created by laser pointer + diffuser + neutral filter)
  - Intensity different at pixel level, but overall homogeneous



ADC Bit-depth and Pixel Format

- 16-bit format
- Dark image ⇒ values packed near zero
- Effects of ADC bit-depth
  - ADC10 ⇒ $2^6 = 64$ is the smallest unit
  - ADC12 ⇒ $2^4 = 16$ is the smallest unit
  - ADC14 ⇒ $2^2 = 4$ is the smallest unit
- **ADC bit-depth decides units in the [0, 65535] space**
- Lowest value not zero, but the smallest unit
  - Interesting… not what I expected



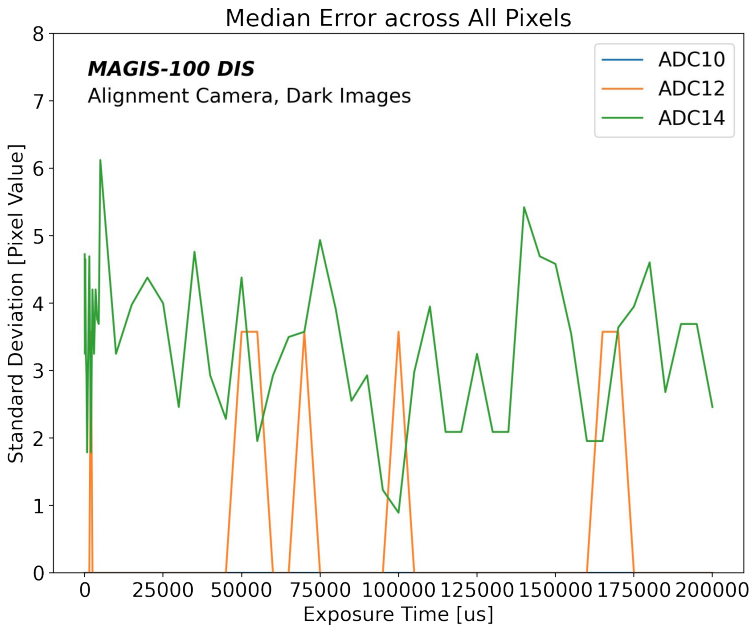
Read-out Noise & Dark Current

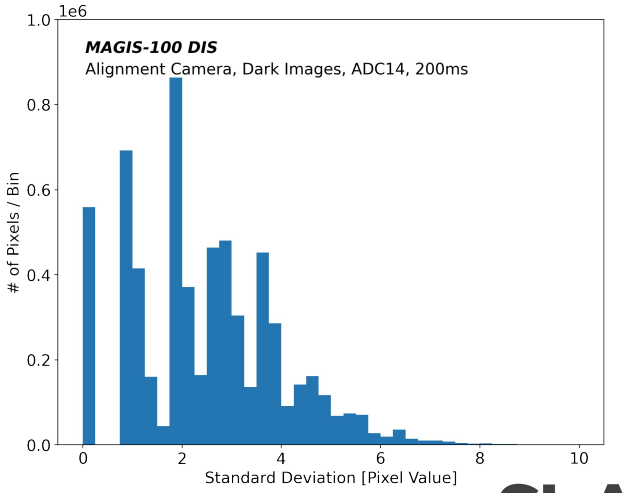
- At each exposure & ADC, we use 20 images to:

$$\sigma(i,j)^2 = \frac{1}{20-1}\sum_{n=1}^{20}\left(p_n(i,j) - \bar{p}_n\right)^2$$

$$\sigma = \text{Median of } \sigma(i,j)$$

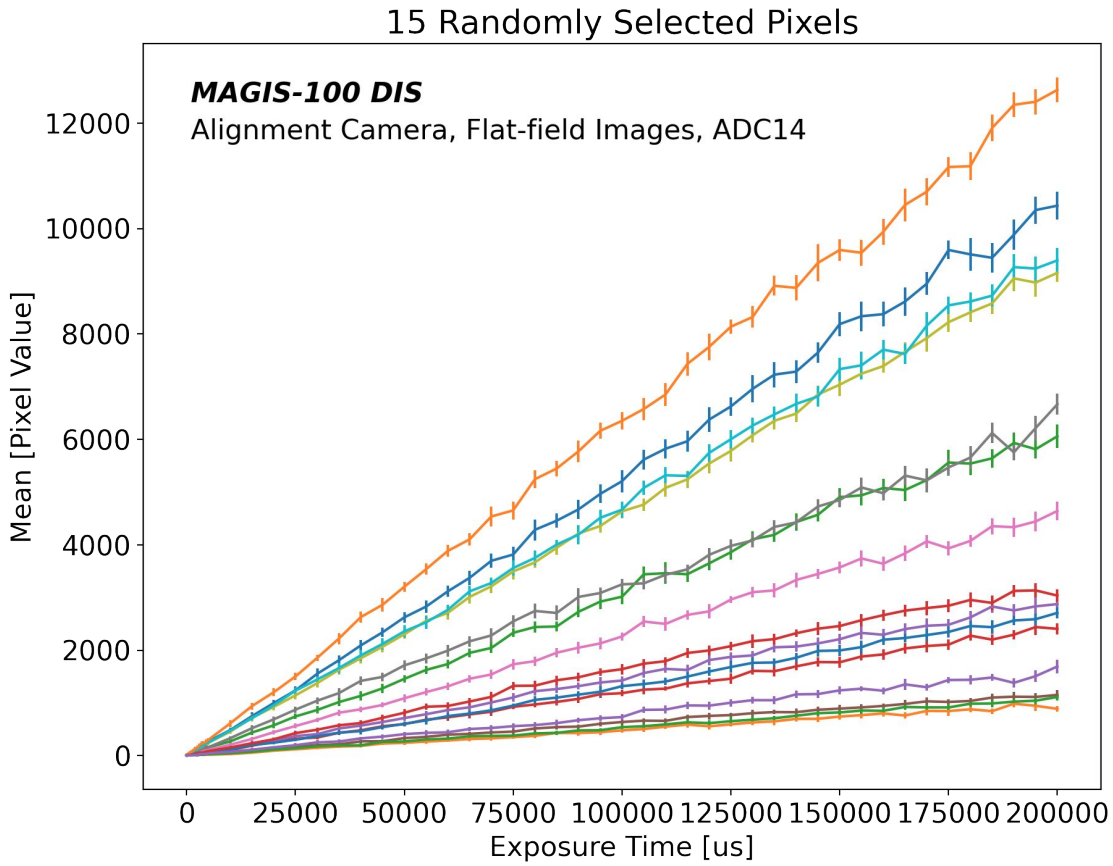
- **No noticeable dependence on t_{exp} ⇒ No noticeable dark current**
- ADC10 & ADC12
  - Smallest signal detectable = $14177e^- / 2^{10}$ & 2^{12} = $13.84e^-$ & $3.46e^-$
  - This is larger than the quoted read noise, $2.55e^-$
  - So, we don't see this read-out error—make sense!
- **ADC14**
  - **4 units in pixel value = 1 ADU = $14177e^- / 2^{14} = 0.87e^-$**
  - **This is much smaller than the quoted read noise, $2.55e^-$**
    - $2.55e^- / 14177e^- \times 65535 = 11.8$ units…
  - **Thoughts…? Problem with statistical analysis…?**





Signal Response

- Flat-field images
  - Constant intensity shining onto each pixel
- **Mean signal clearly linear with t_{exp}**

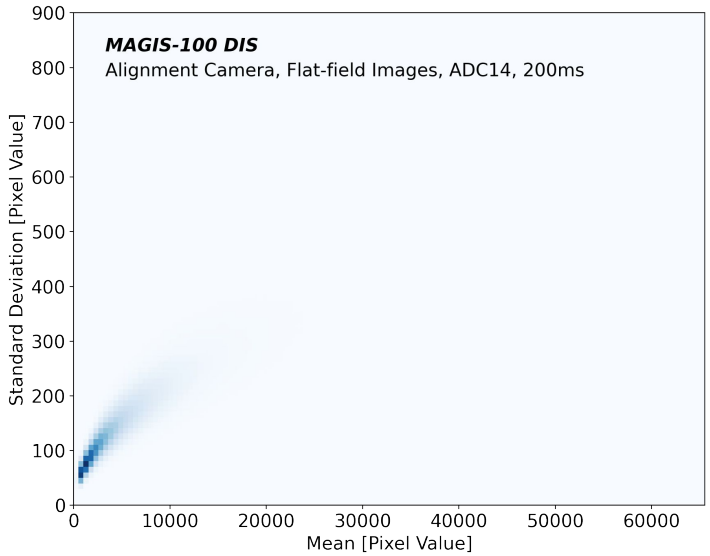


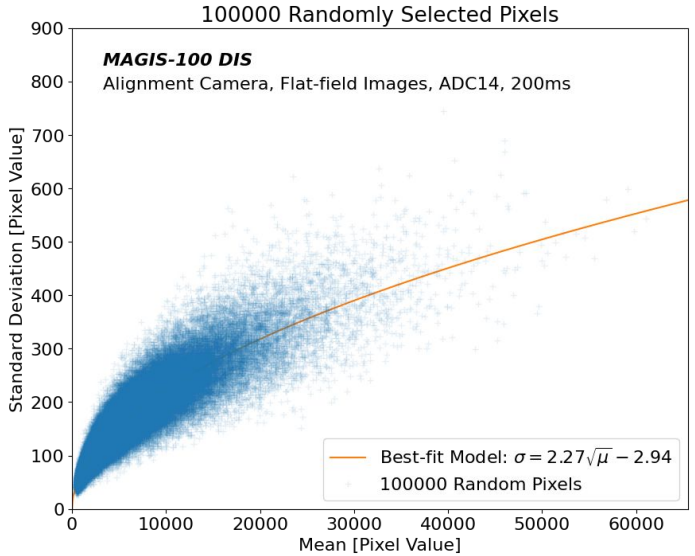
Photon Shot Noise

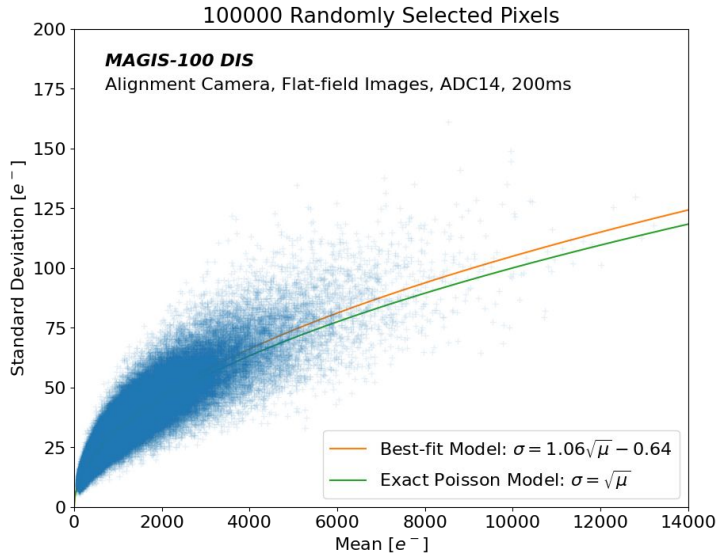
- Noise expected to be Poisson
- **Expectation seems to hold**
  - Constant and other terms: negligible contribution
  - Reverting ADC (pixel value → ADU → electrons), we get close to exact Poisson as expected

$$\sigma(i,j) \sim \sqrt{\mu(i,j)}$$

(Reverting all the way back to photons is possible, but requires simulating negative binomial dist.)







Summary

Preliminary analysis of DIS camera DAQ

- ADC bit-depth & pixel format
  - **Seems to operate as expected**—Smallest unit = $2^{(\text{pixel format - ADC bit})}$
- Read noise
  - **No dependence on t_{exp}—dark current seems negligible**
  - **ADC14 shows mean read noise of ~4 units, corresponding to 0.87e-, but this seems too low, given quoted read noise of 2.55e-**
- Signal response & photon shot noise
  - **Response is linear, noise seems Poisson**
- TODO
  - Add QE, saturation, ADC, and digital formatting to `gradoptics`
  - Further study/understand read noise issue
  - Analyze read-out slope and study global reset behavior