Extreme faint flux imaging with an EMCCD

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OBSERVATOIRE DU MONT MÉGANTIC

Photon etc. A spectrum of solutions

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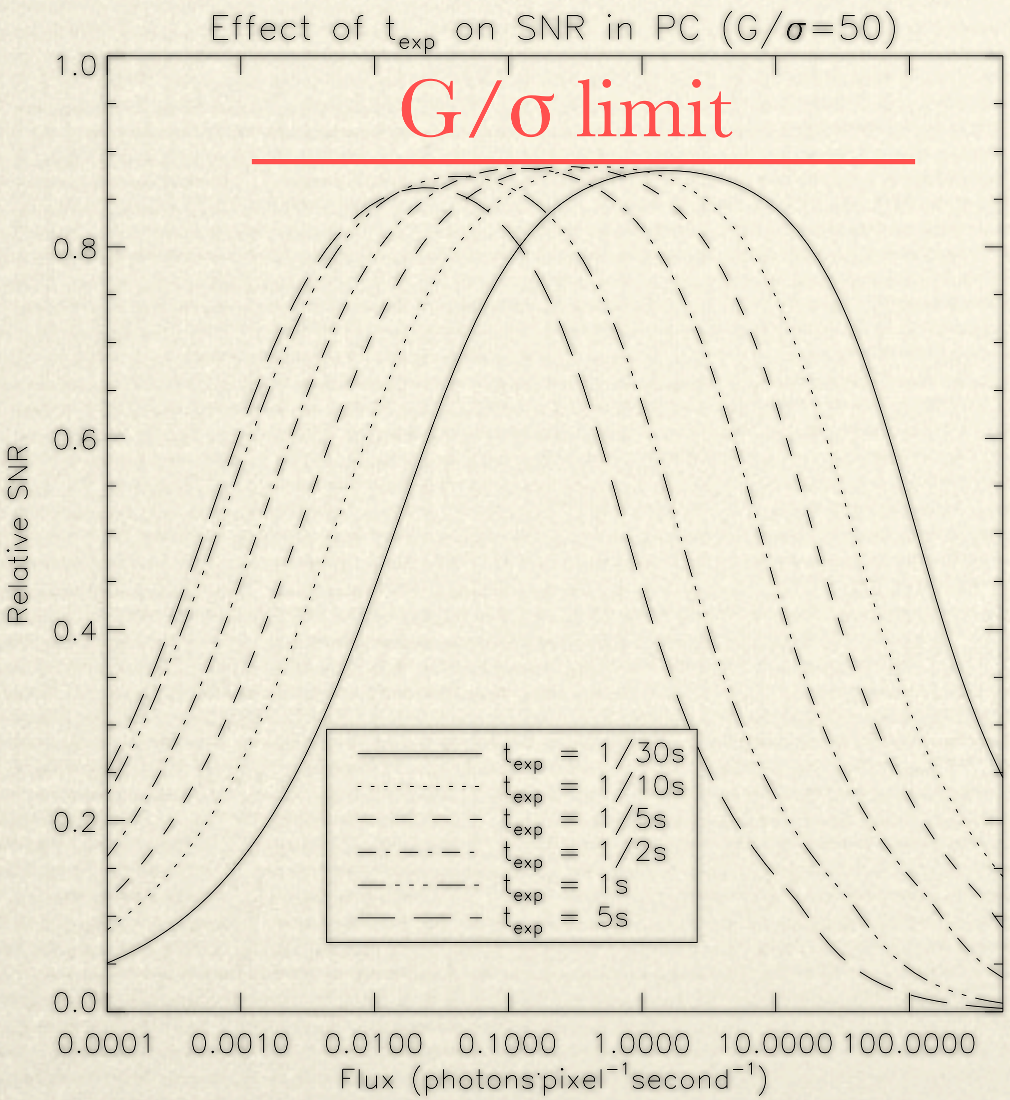
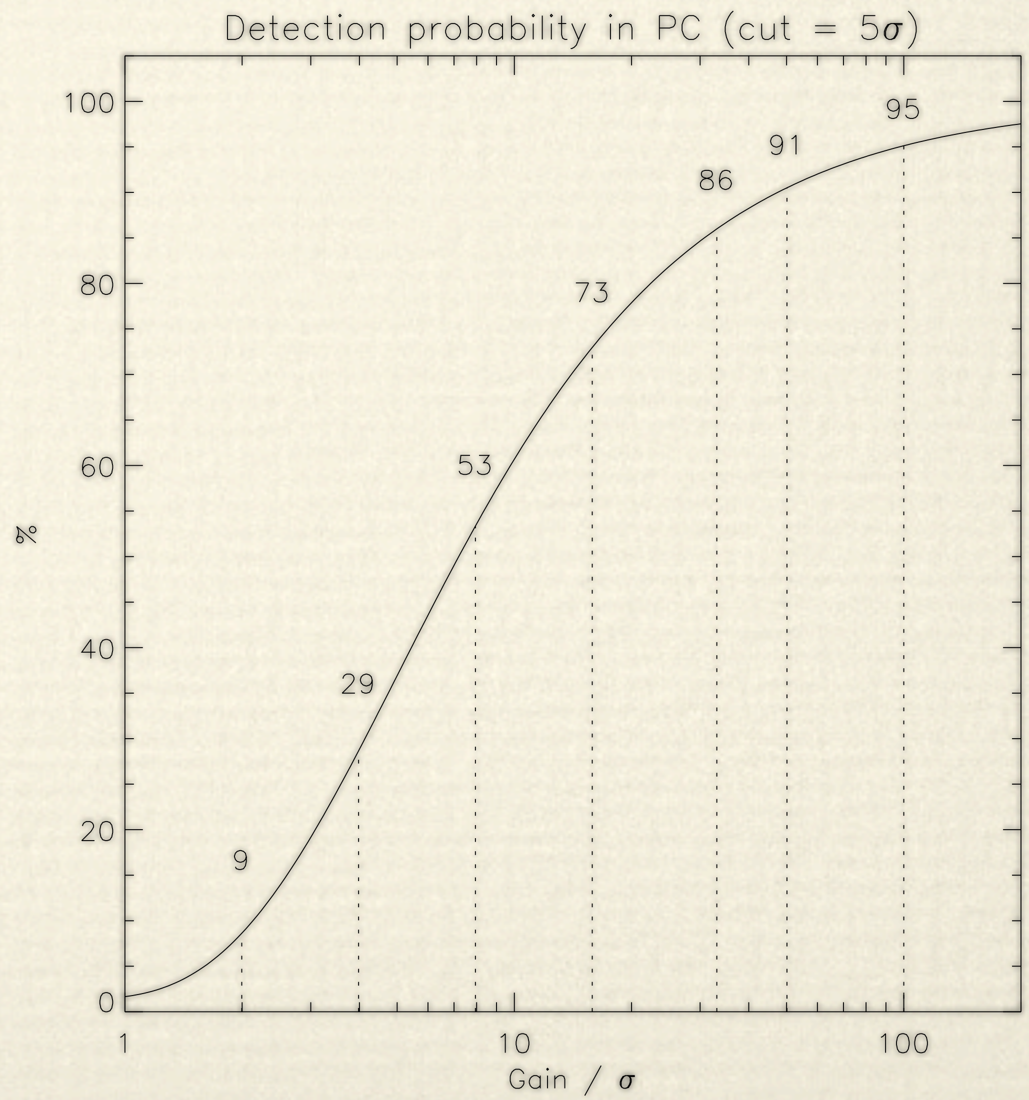
EMCCD challenges

- In order to get rid of the excess noise factor, the Photon Counting (single threshold, PC) operation of the EMCCD is mandatory
- PC operation implies moderate to high frame rate
- At high frame rate, Clock Induced Charges (CIC) are the dominant source of noise
- CIC must be tamed down to allow efficient PC operation
- We want inverted mode operation

EMCCD challenges

- In PC, a high G/σ ratio is mandatory to allow a high proportion of the events to come out of the read-out noise





The CCCP Controller

- The CCD Controller for Counting Photons was built to test ways to reduce the CIC. It comprises :
  - 13 arbitrary clocks: BYOW*
    - 12 bits DAC, 10 ns resolution on every clock
  - 1 resonant HV clock (14 bits DAC for amplitude)
    - 1 ns switching precision
  - Biases, 16 bits ADC (w/ CDS), Communication interface

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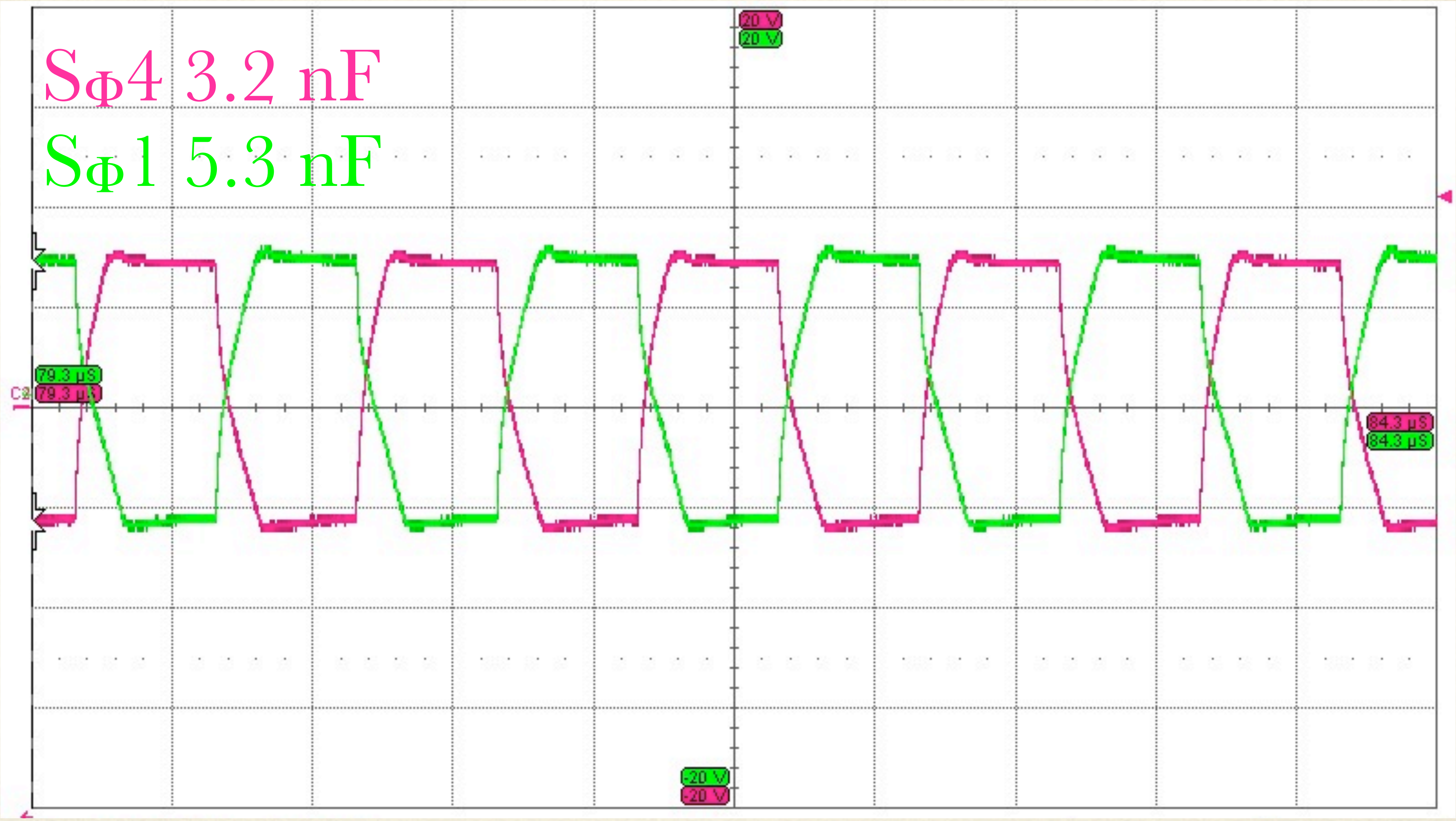
*Build Your Own Waveforms

BYOW - Vertical

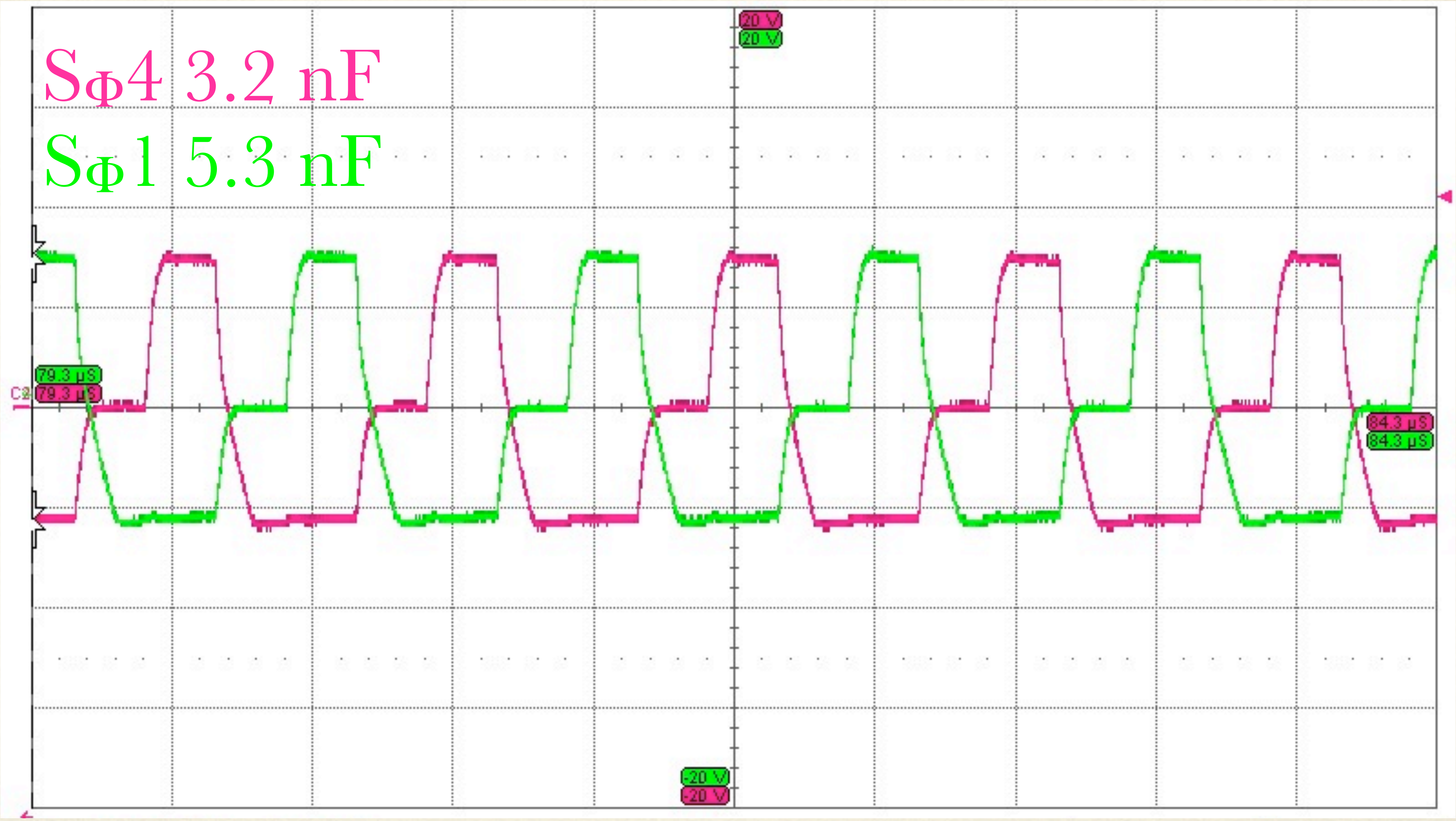
- Scope traces: 500ns - 5V / div



Square – 1 MHz

BYOW - Vertical

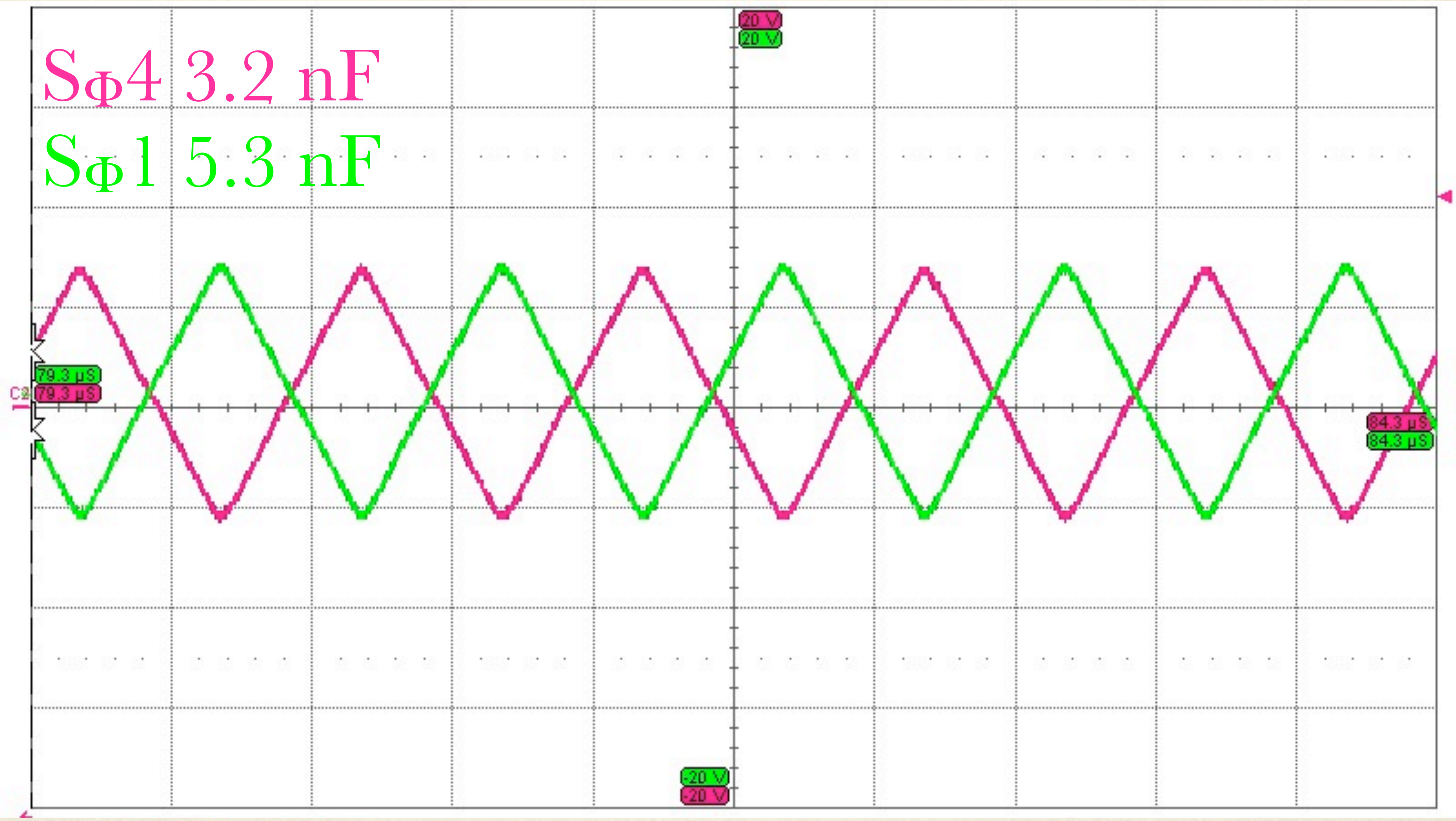
- Scope traces: 500ns - 5V / div



Tri level – 1 MHz

BYOW - Vertical

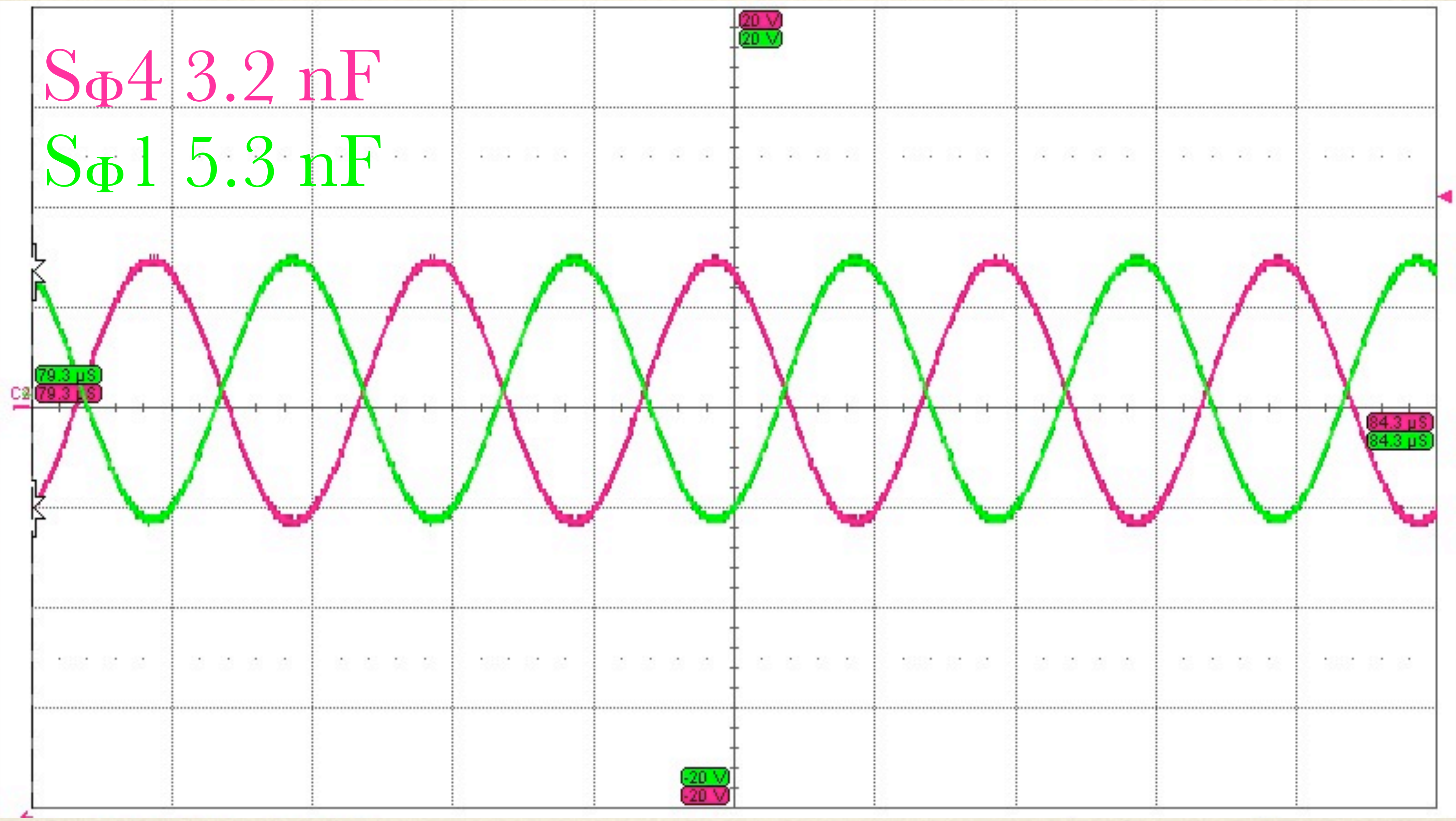
- Scope traces: 500ns - 5V / div



Triangle – 1 MHz

BYOW - Vertical

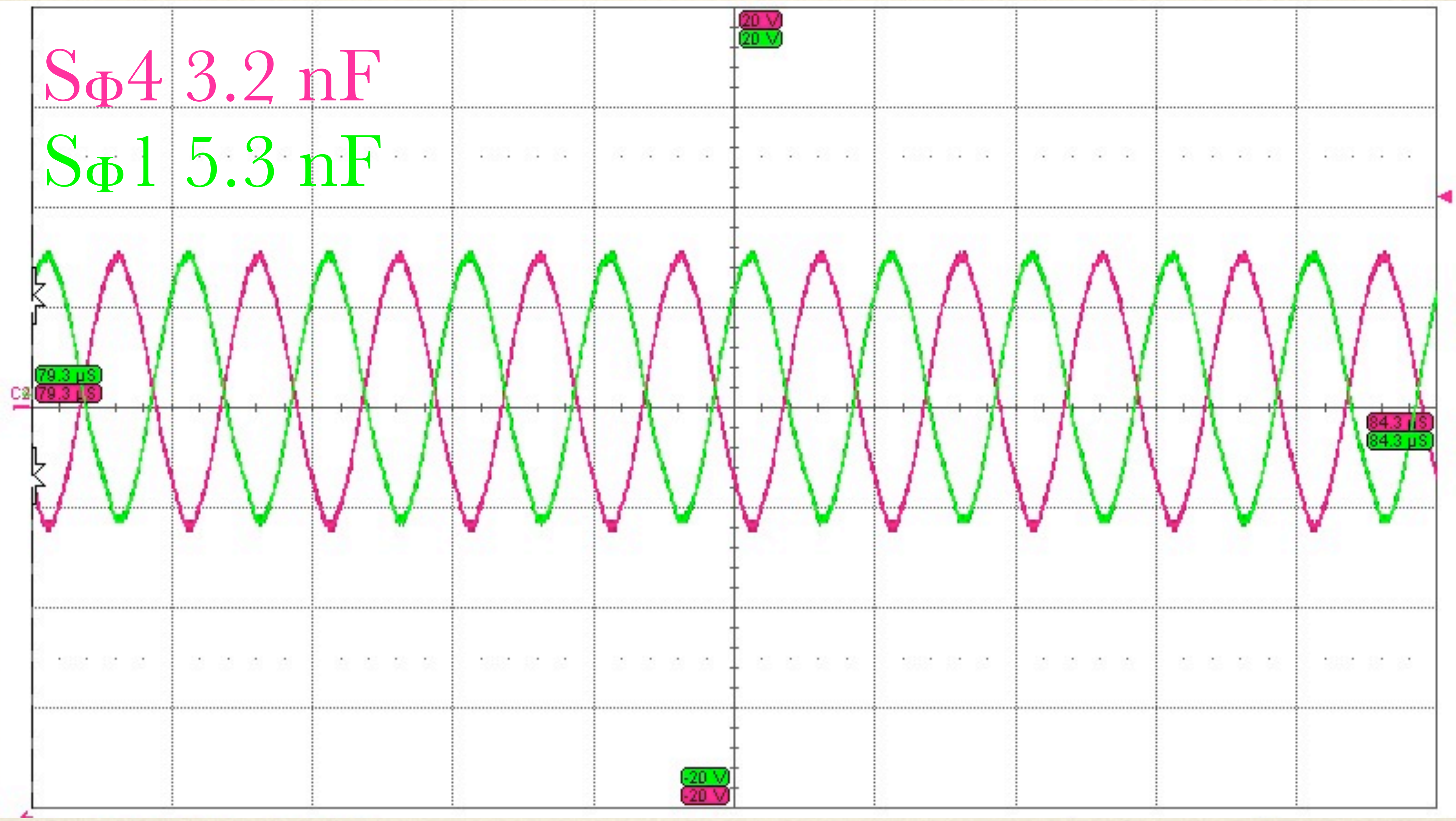
- Scope traces: 500ns - 5V / div



Sinus – 1 MHz

BYOW - Vertical

- Scope traces: 500ns - 5V / div

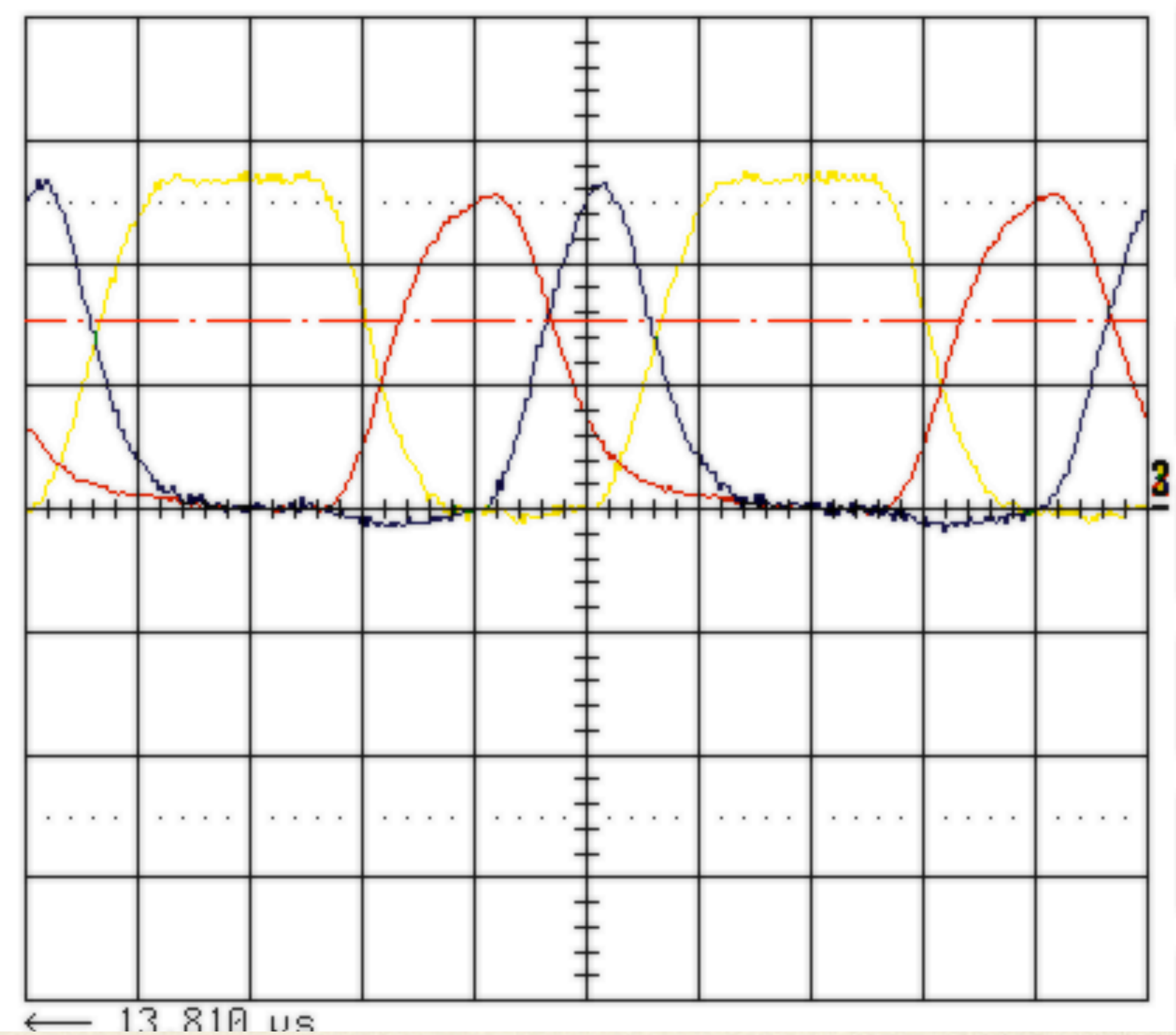


Sinus – 2 MHz

BYOW - Horizontal

- Scope traces: 20ns - 5V / div

RΦ1 115 pF
RΦ2 65 pF
RΦ3 125 pF

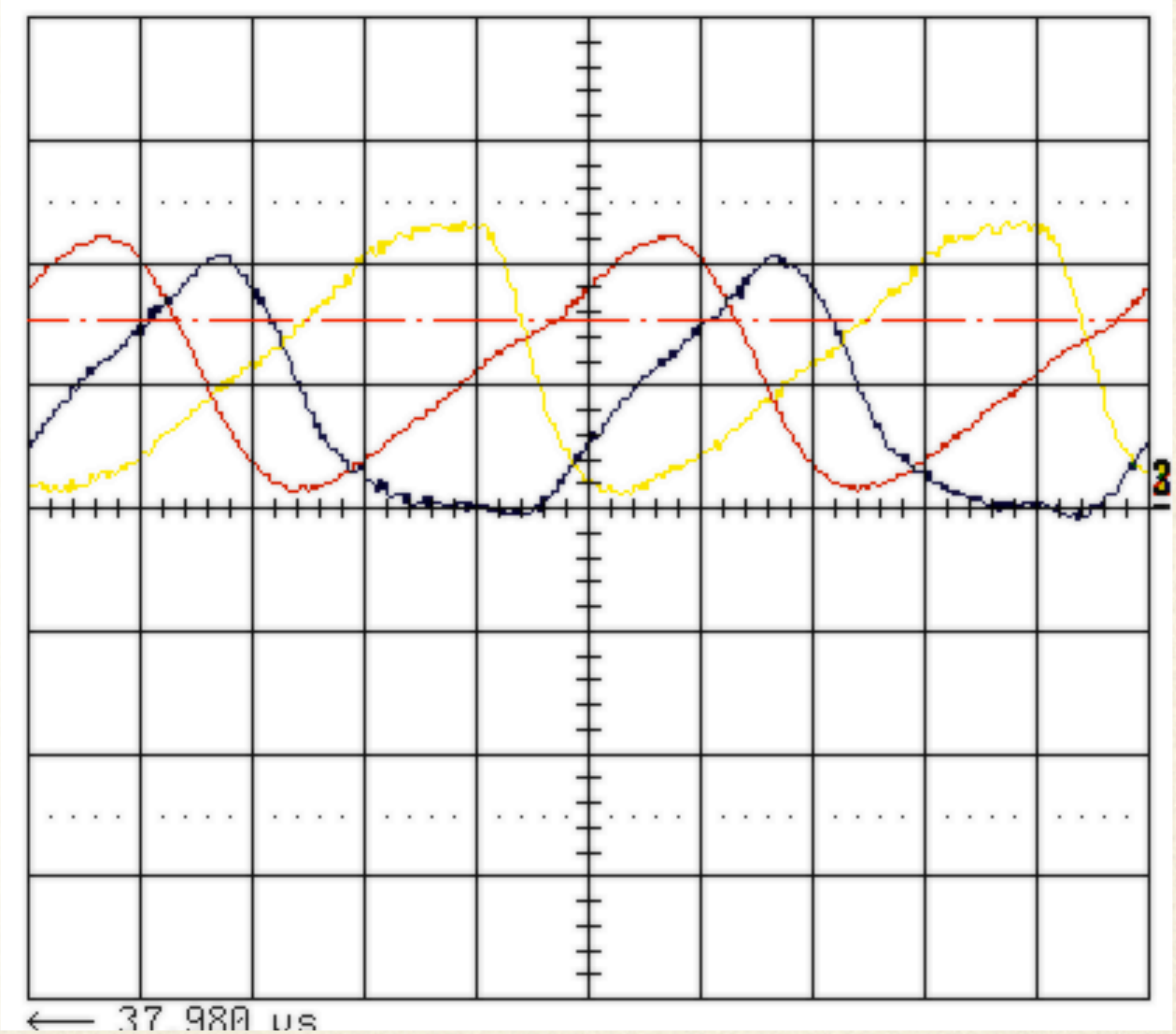


Square – 10 MHz

BYOW - Horizontal

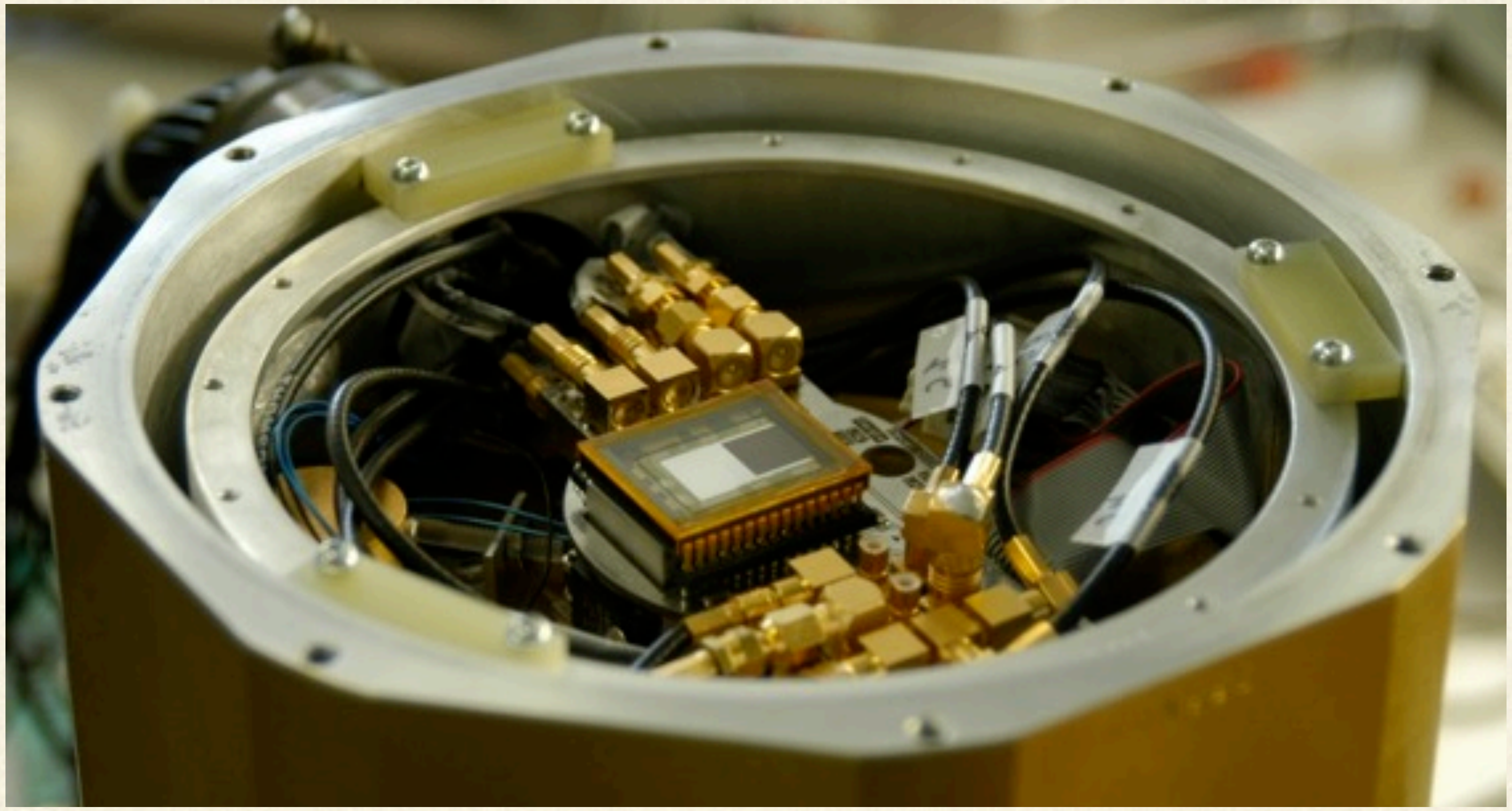
- Scope traces: 20ns - 5V / div

RΦ1 115 pF
RΦ2 65 pF
RΦ3 125 pF



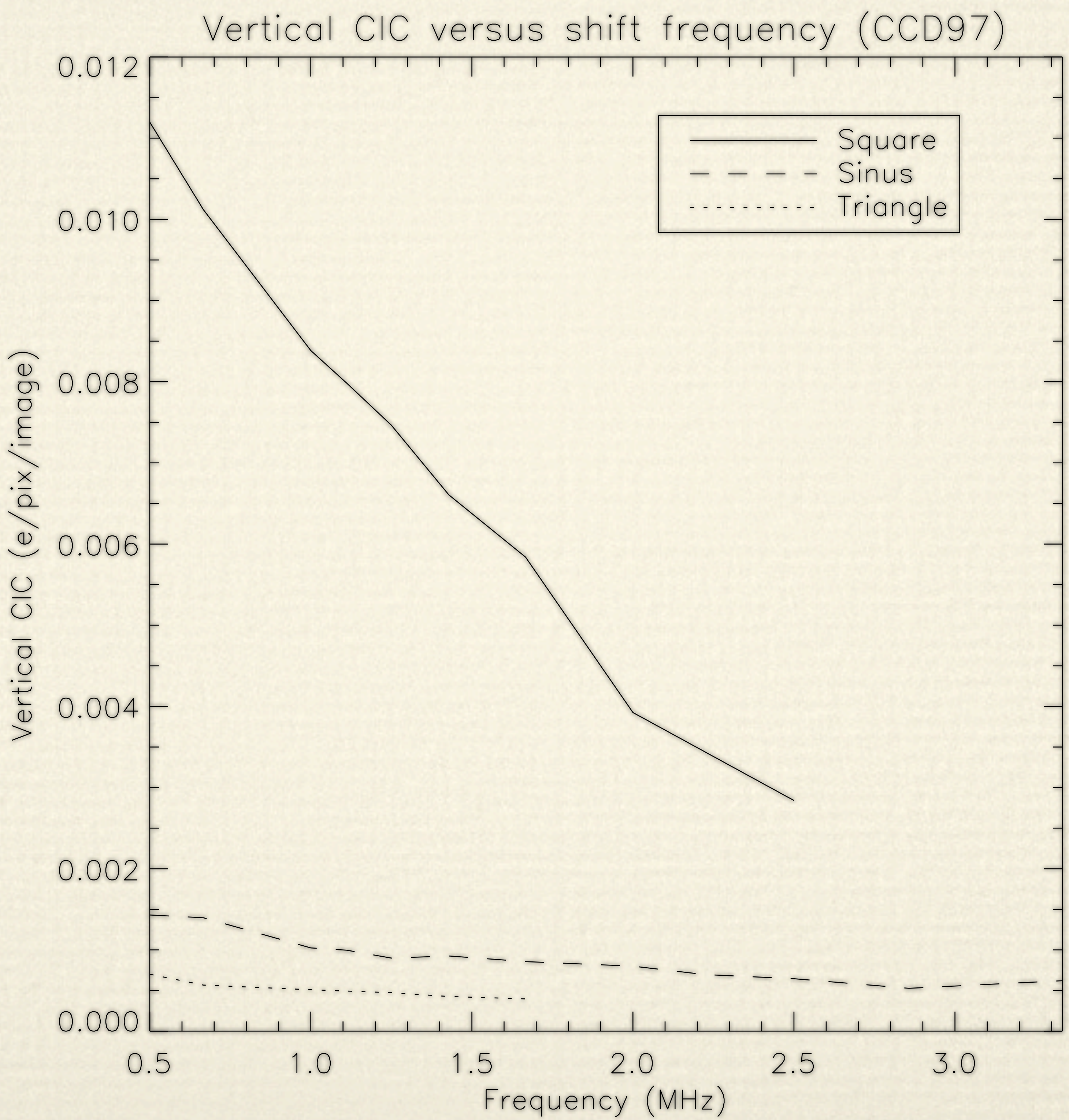
Triangle, asymmetric – 10 MHz

Results



- Camera built with CCCP w/ Grade 1 CCD97
- LN_2 cooled

Effect on vertical CIC



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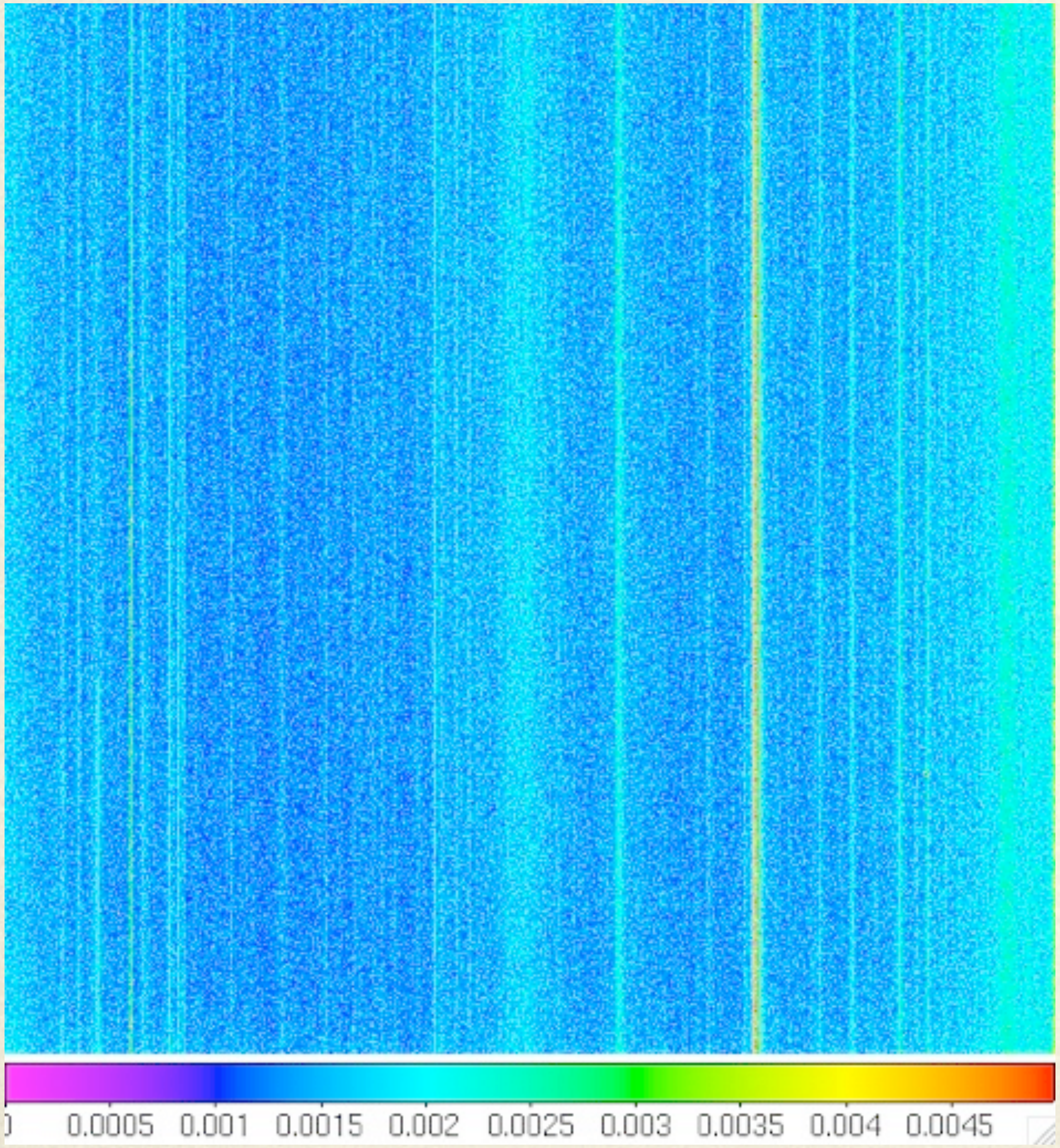
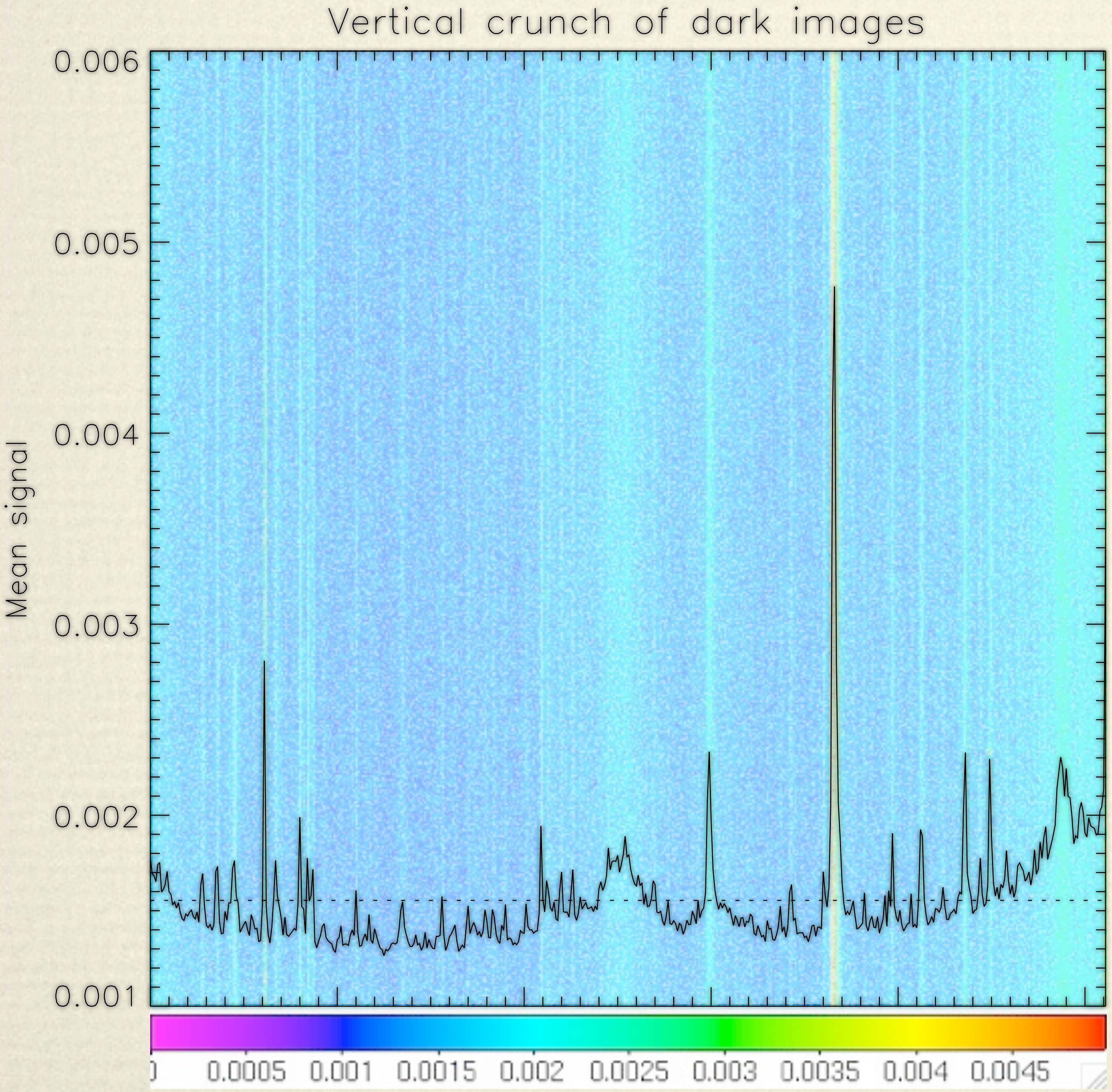


- High SNR dark image
- Some regions of the image are nearly free of vertical CIC

Effect on vertical CIC



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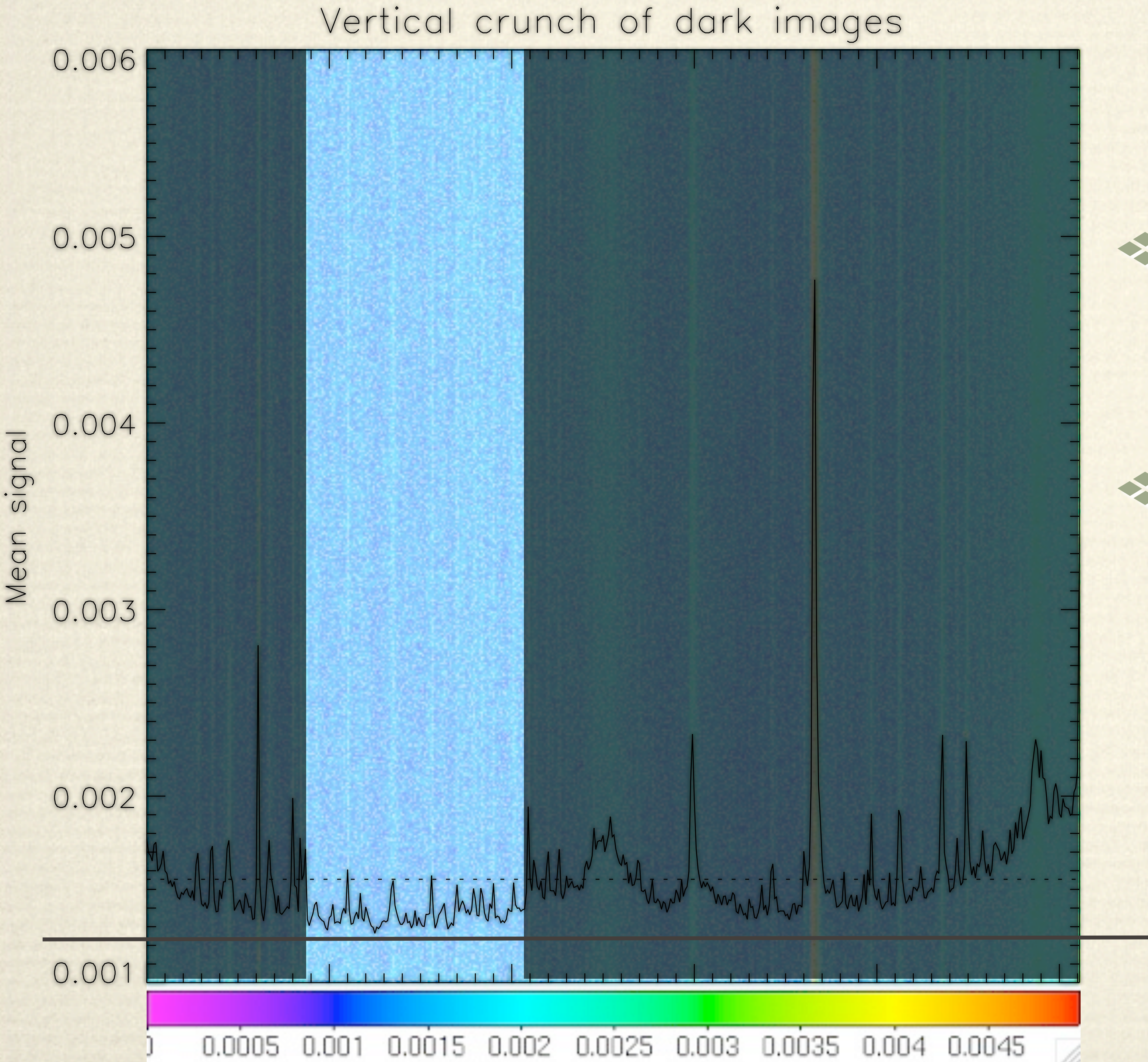
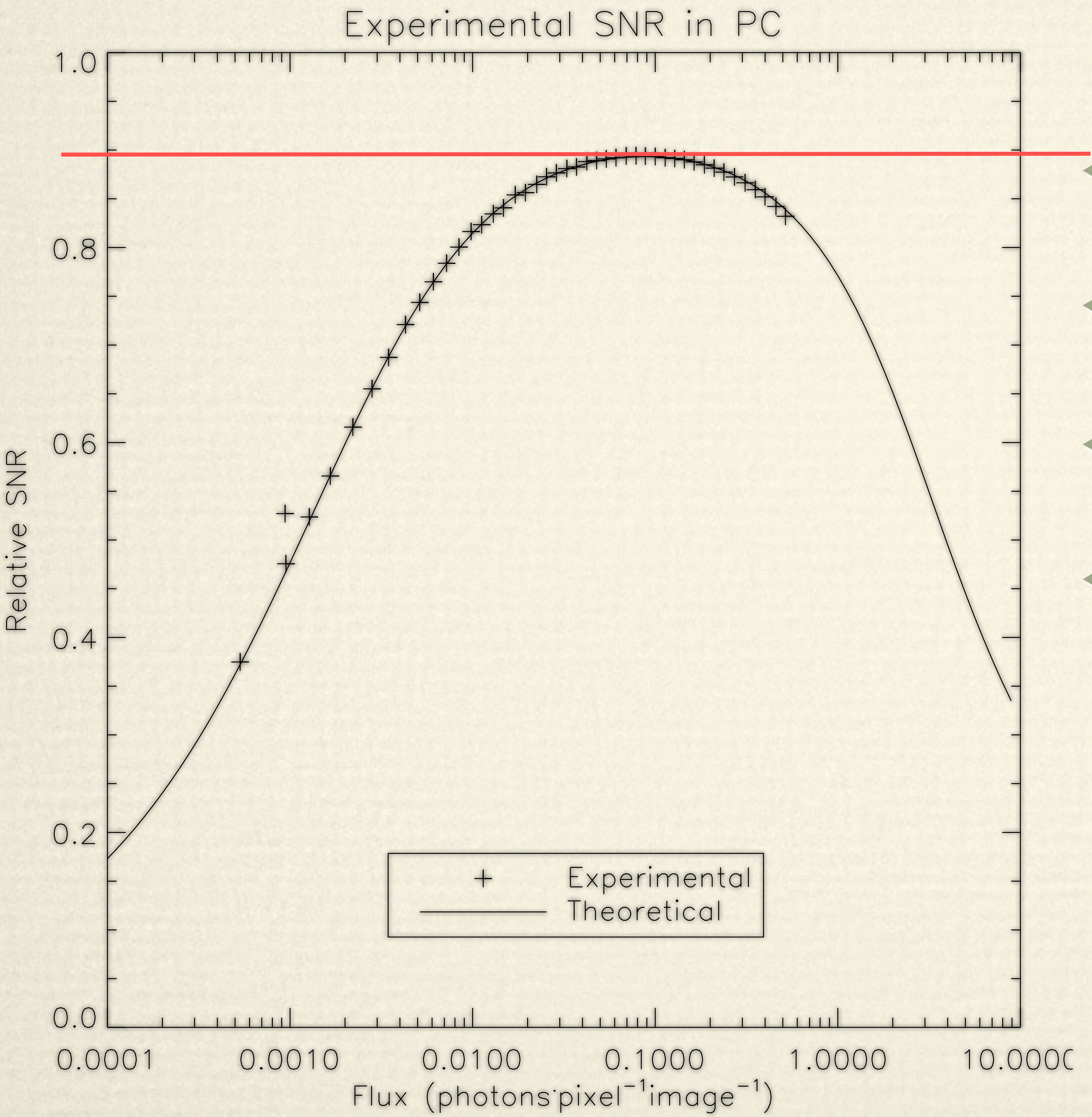


← Horizontal CIC floor

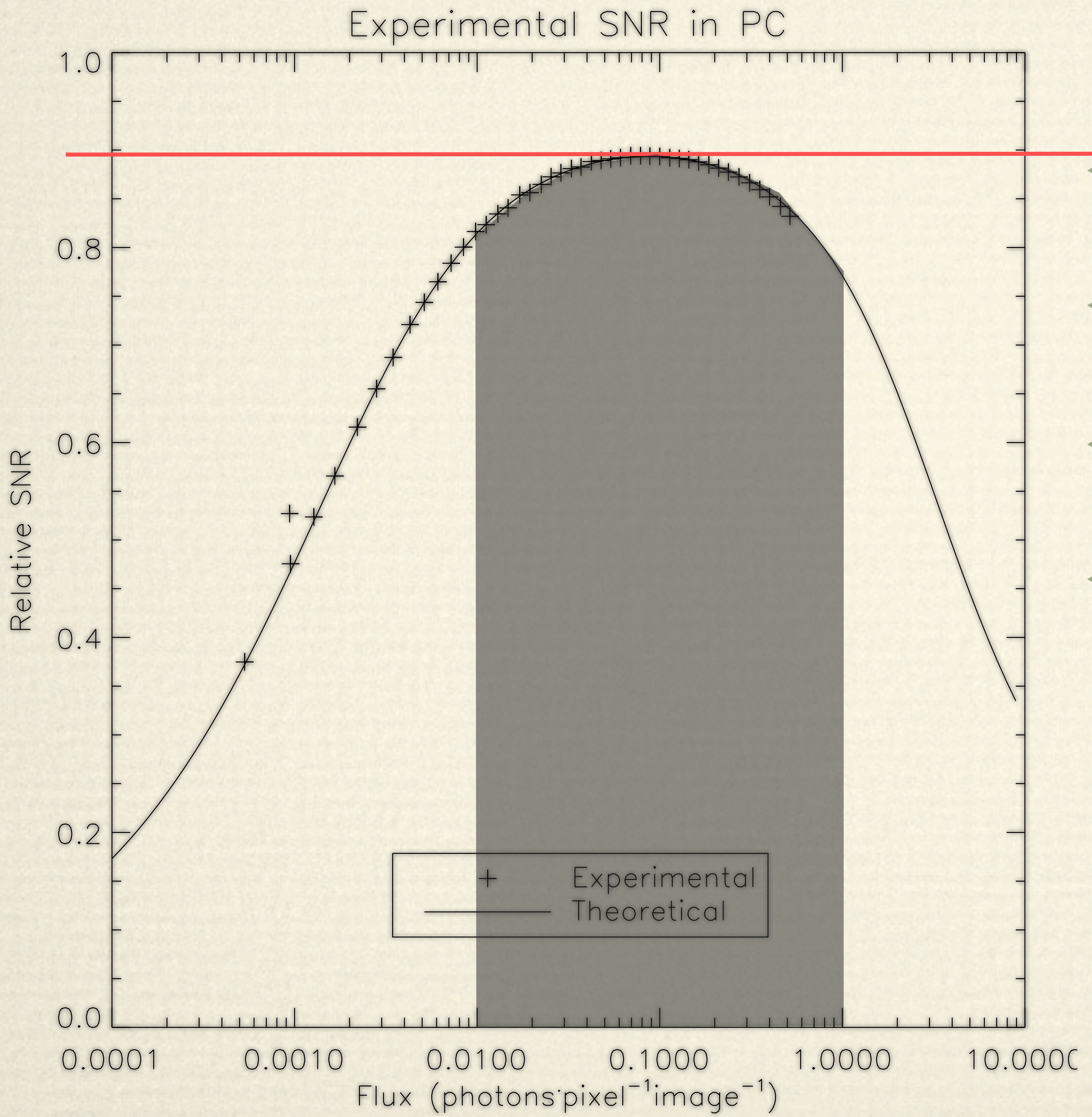
- High SNR dark image
- Some regions of the image are nearly free of vertical CIC

Effect on SNR



- $G/\sigma = 33$ ($\sigma_{eff} = 0.03\bar{e}$)
- $T_{exp} = 0.05$s, 86000 im
- 5σ threshold
- Total CIC + dark:
  - PC: 0.0023 event/pix/im
  - AM: 0.0016 ē/pix/im

Effect on SNR



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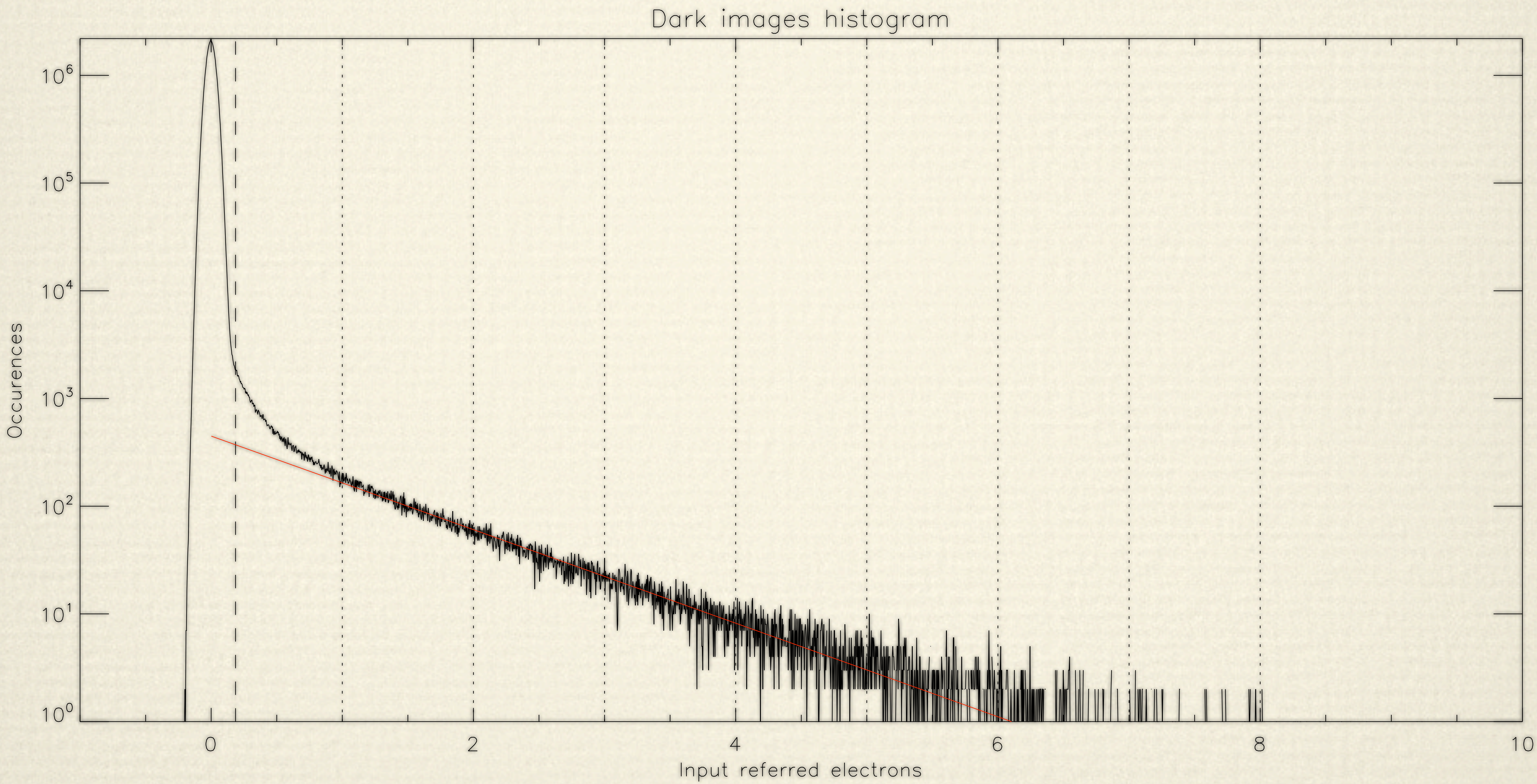
PC CIC+dark ≠ AM CIC+dark



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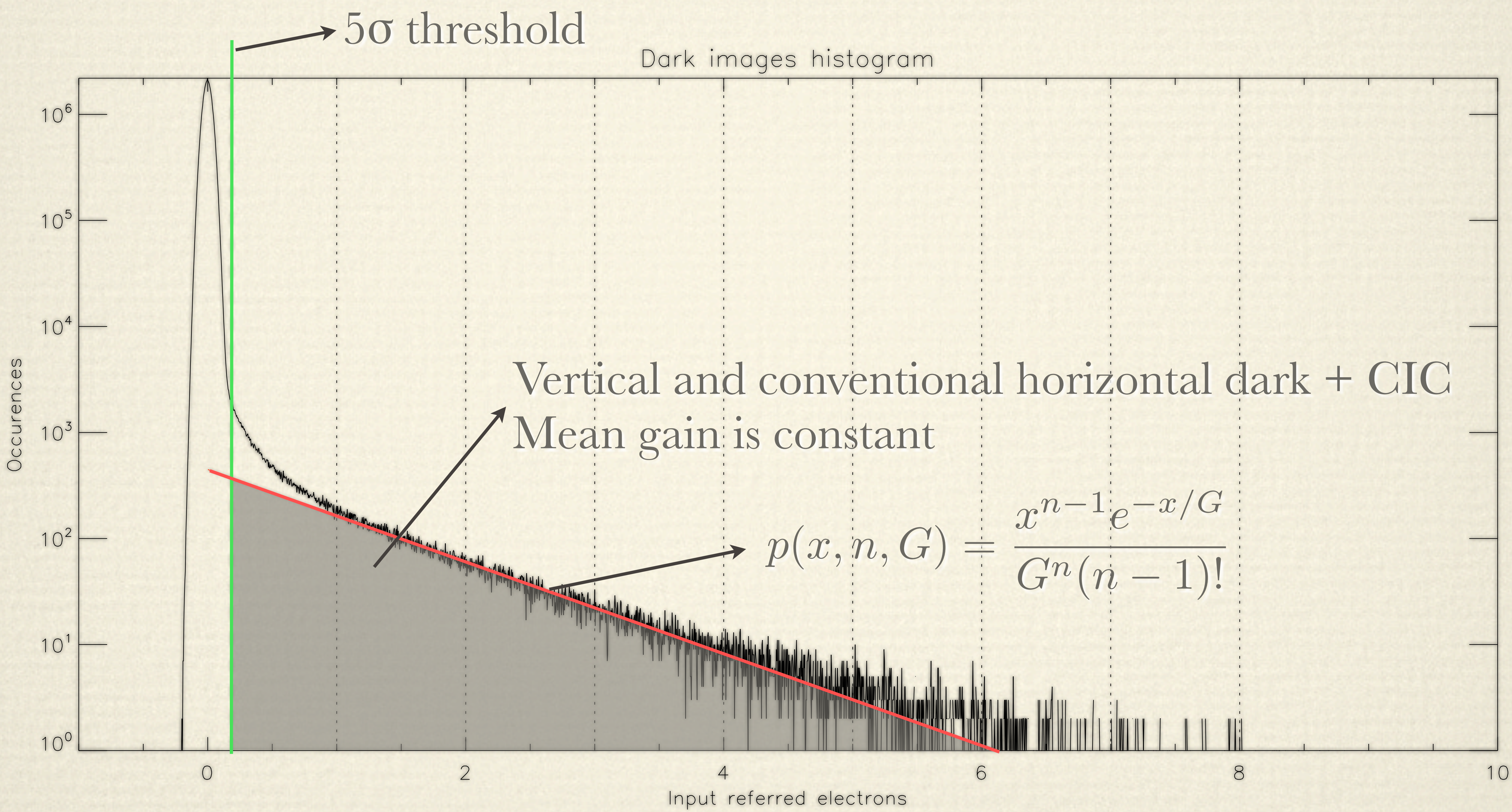

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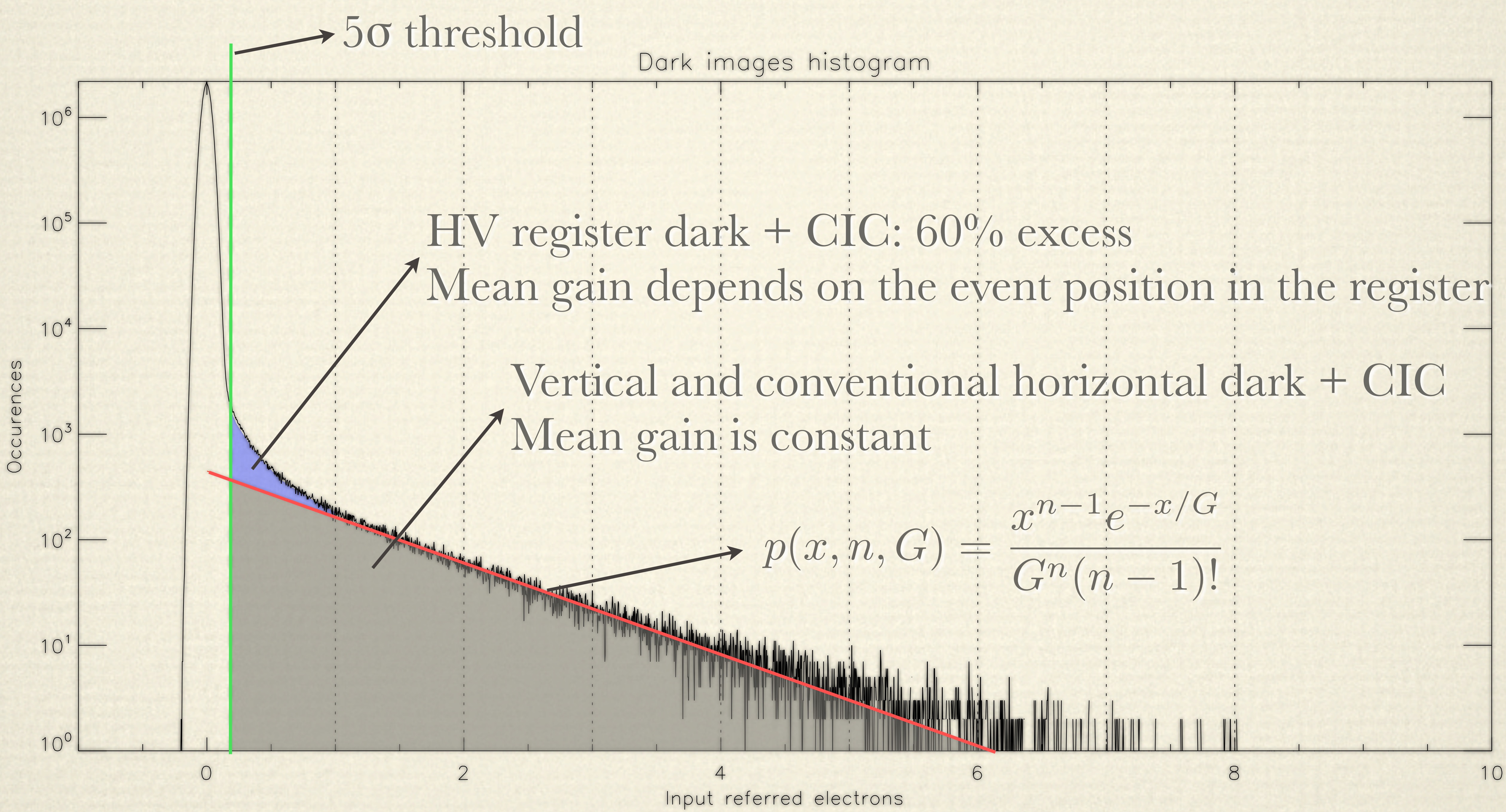
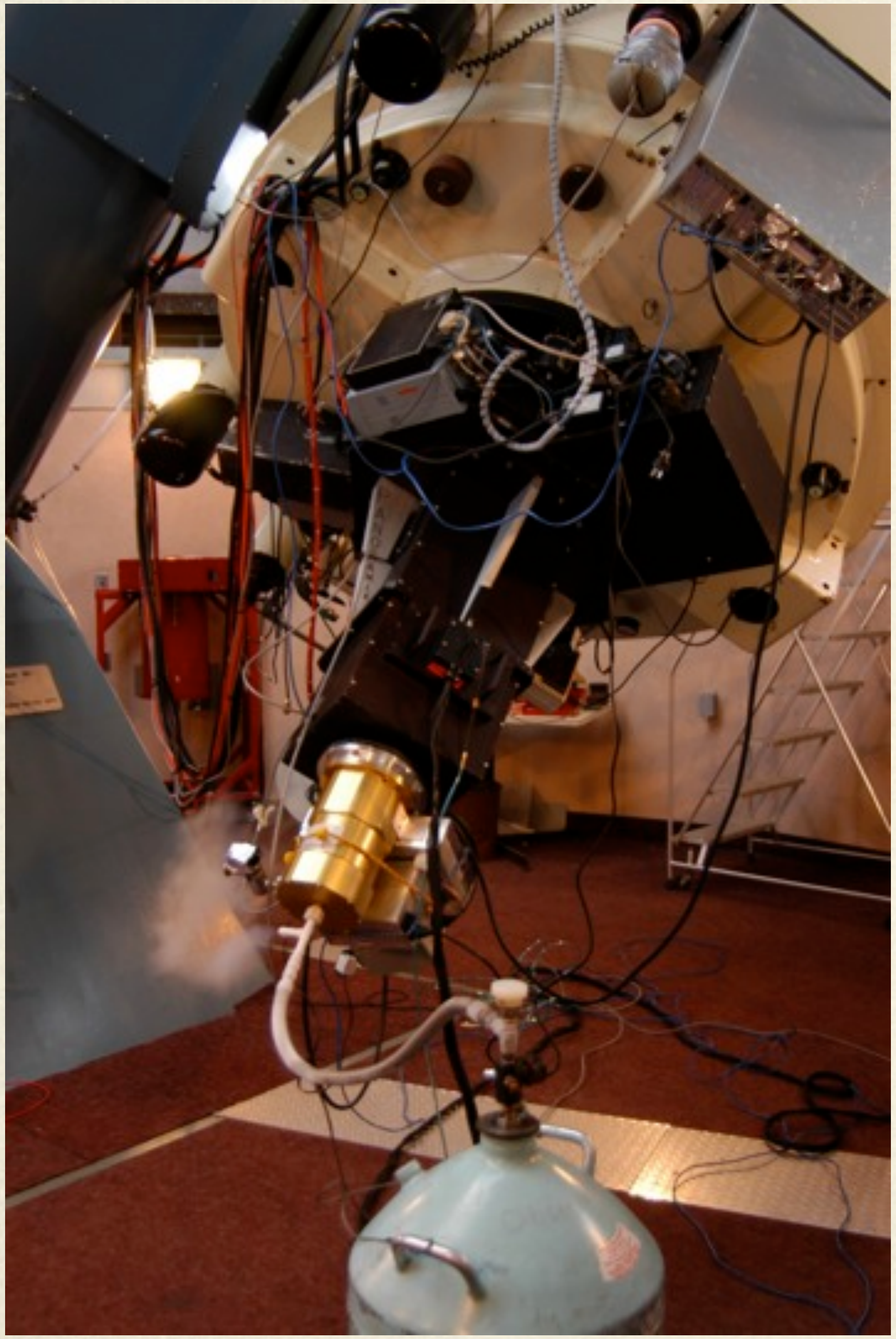
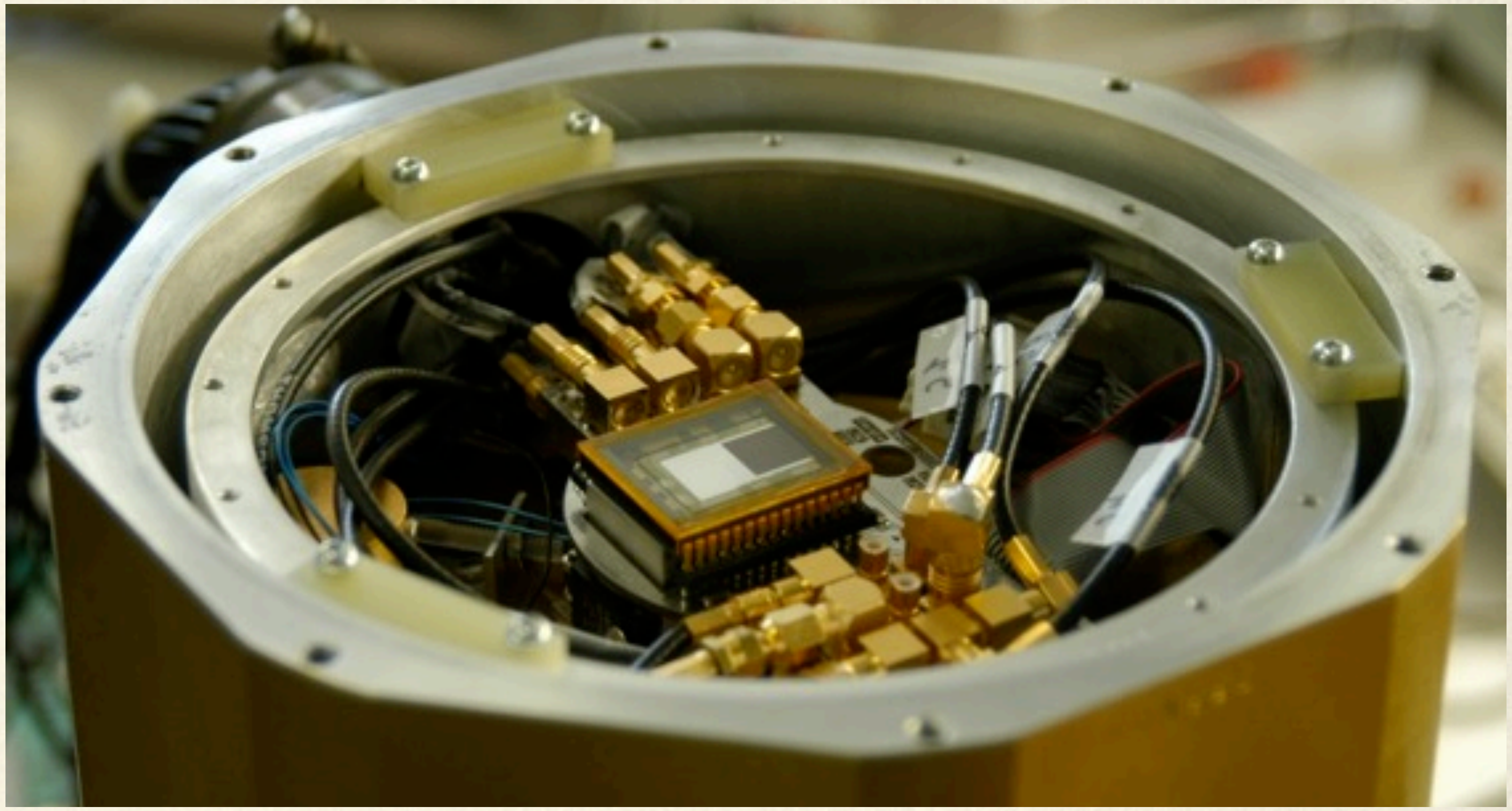


Scientific results

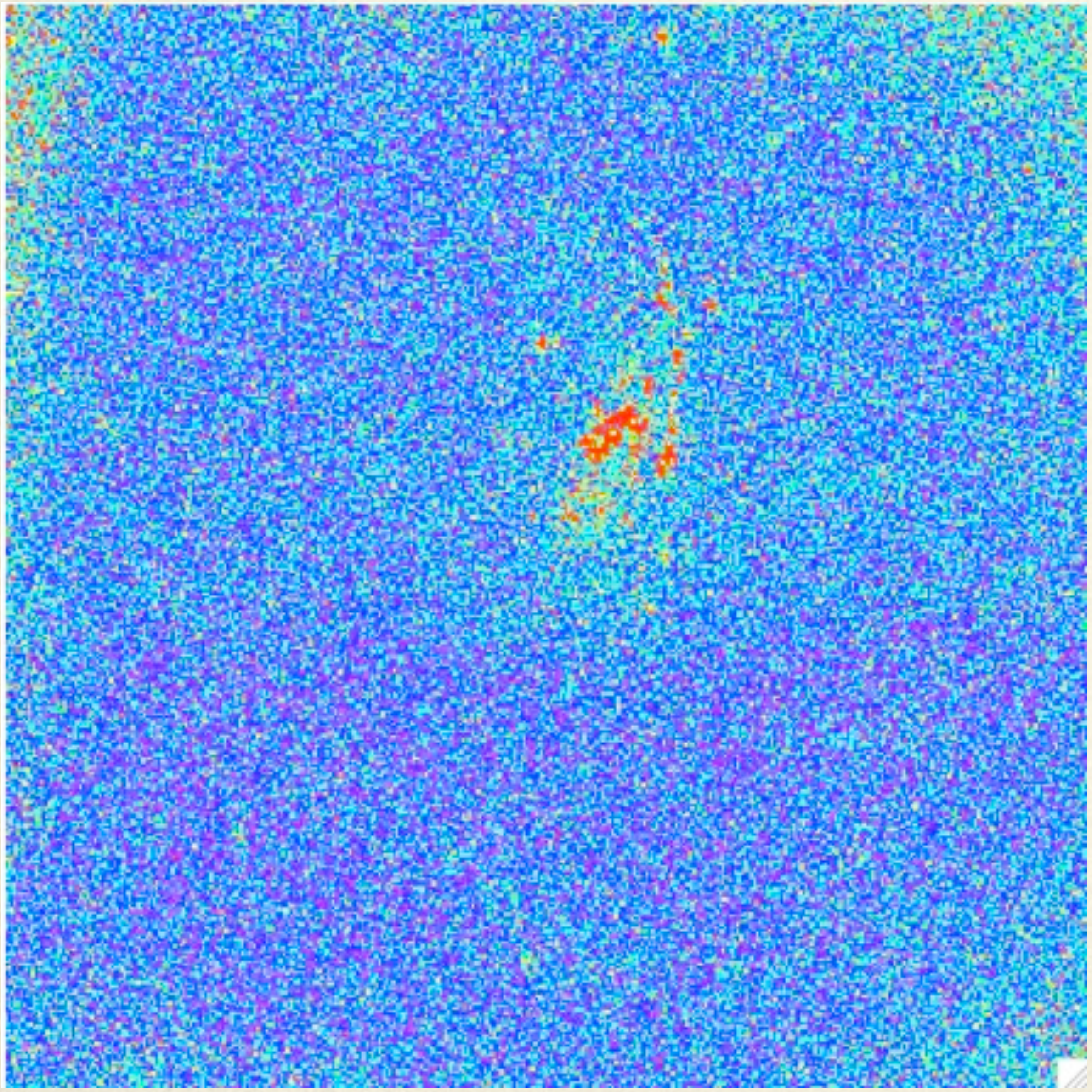




- CCCP w/ Grade 1 CCD97
- OMM Telescope: 1.6-meter, f/2
  - Integral field spectroscopy
  - Narrow band, fast photometry

Integral field spectroscopy

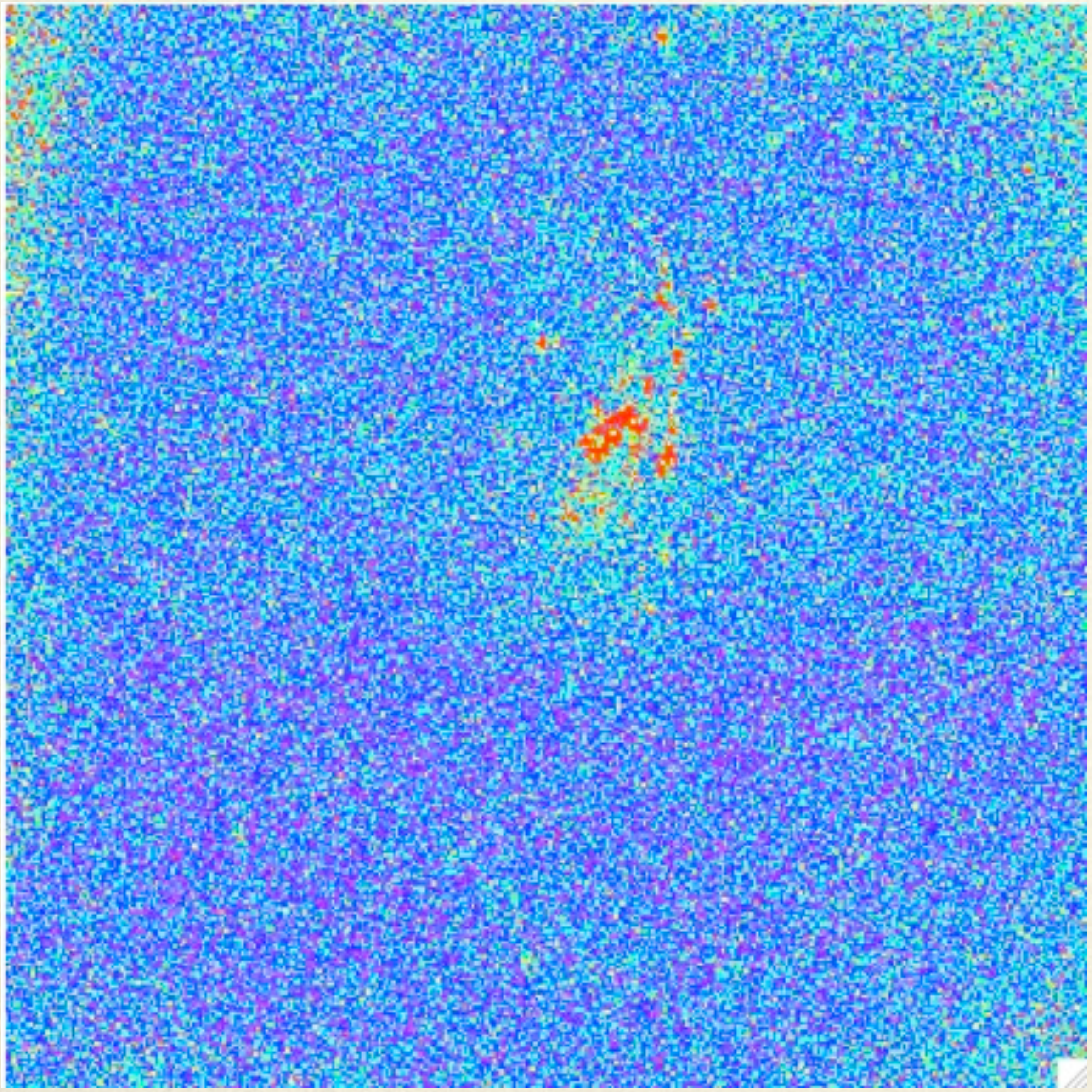
Monochromatic Hα intensity maps



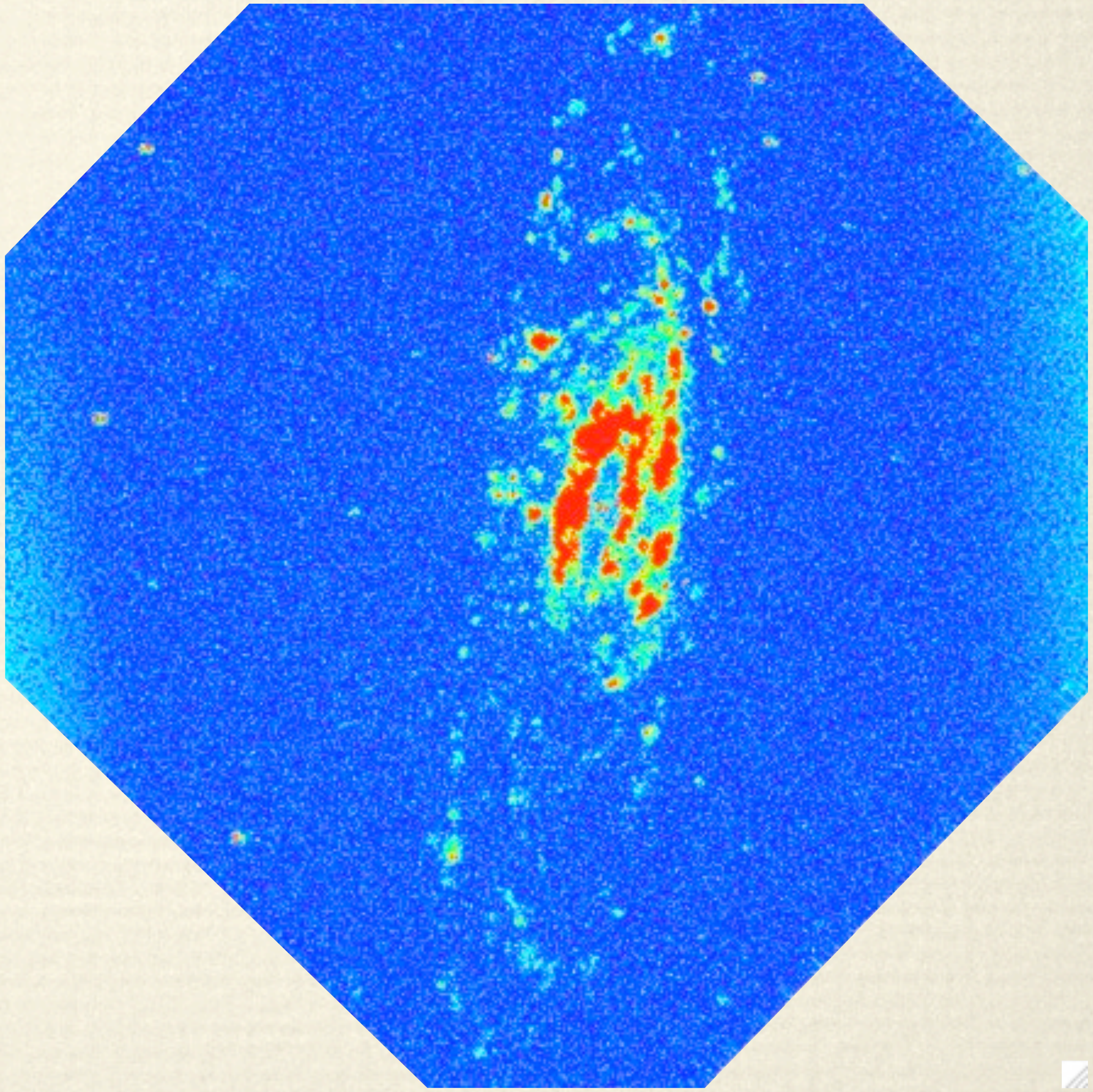
GaAs IPCS

Integral field spectroscopy

Monochromatic Hα intensity maps

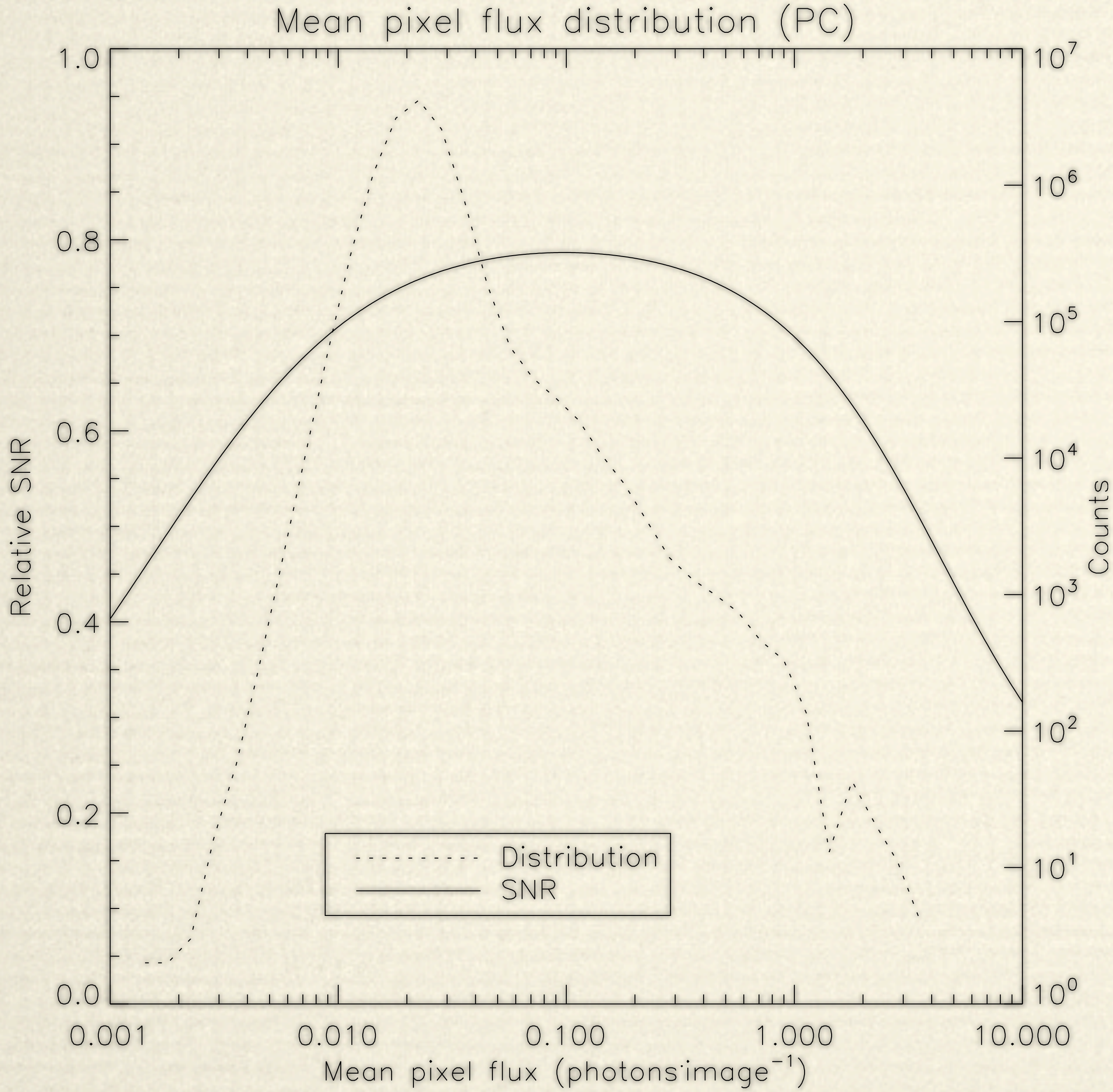


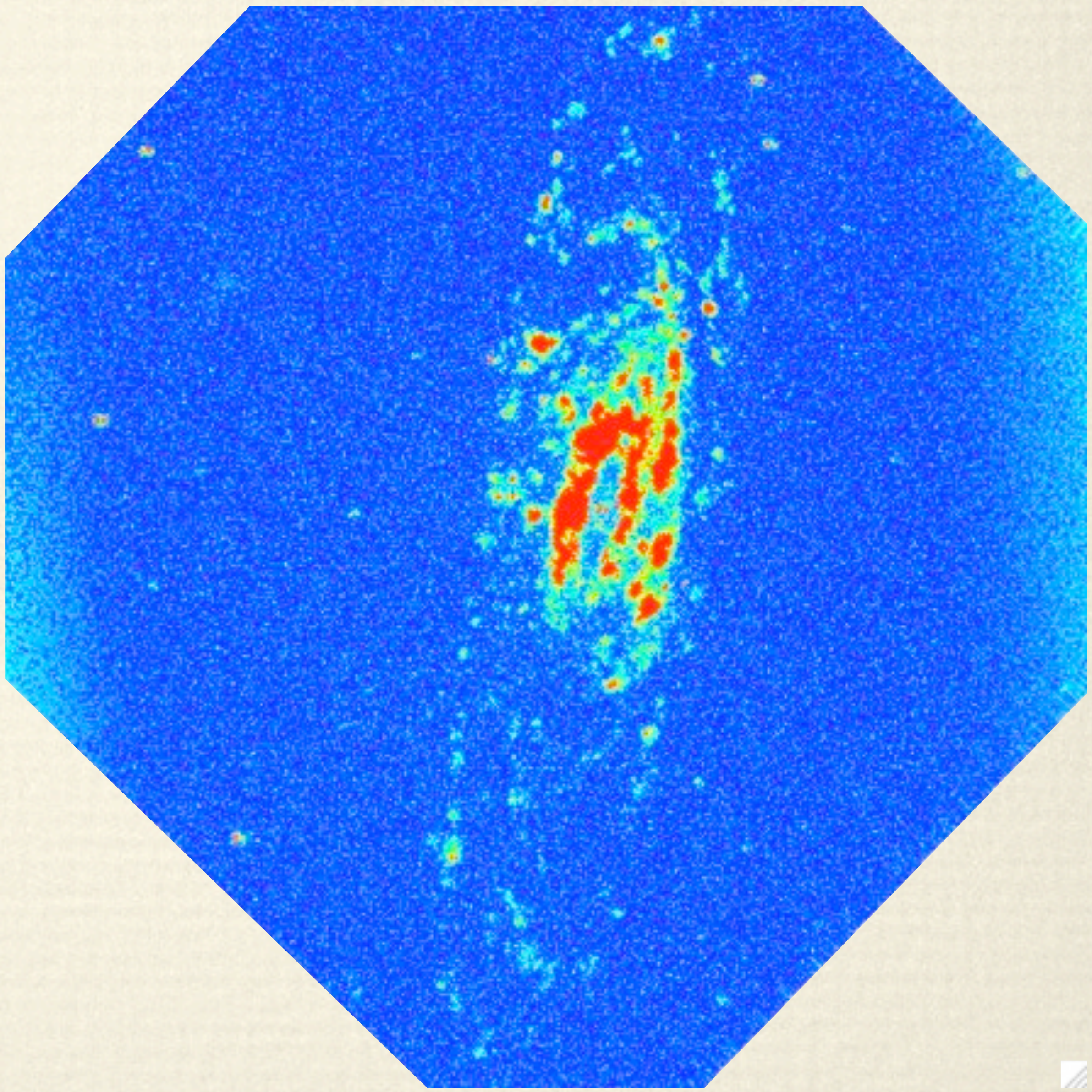
GaAs IPCS



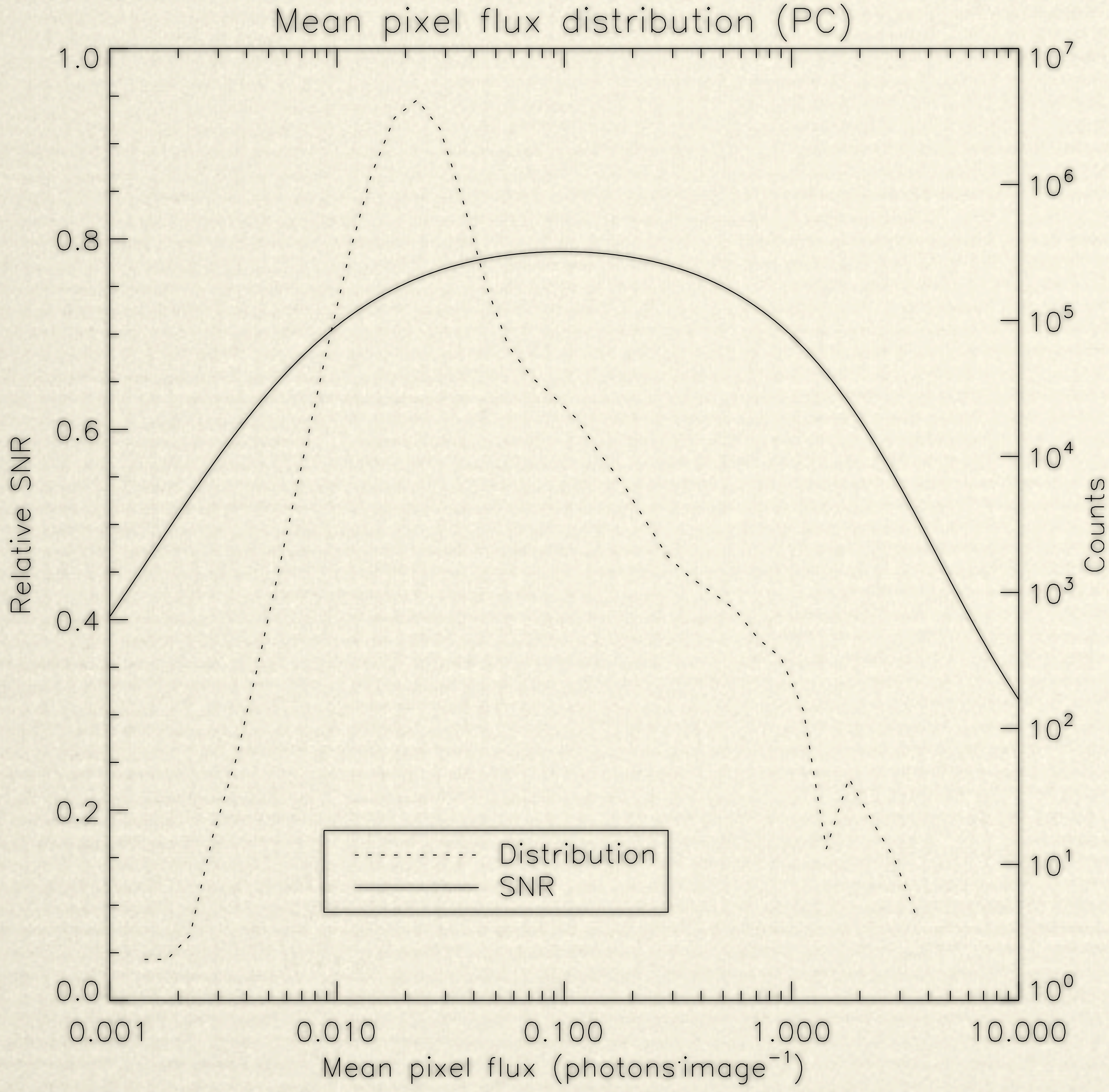
CCCP w/ CCD97

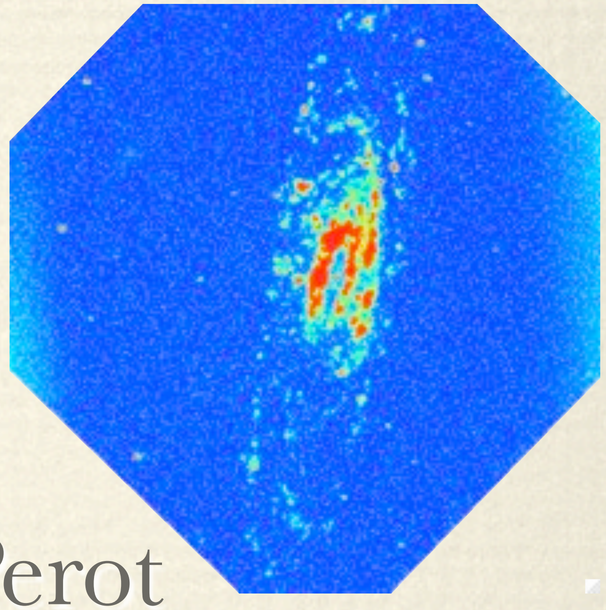
Integral field spectroscopy





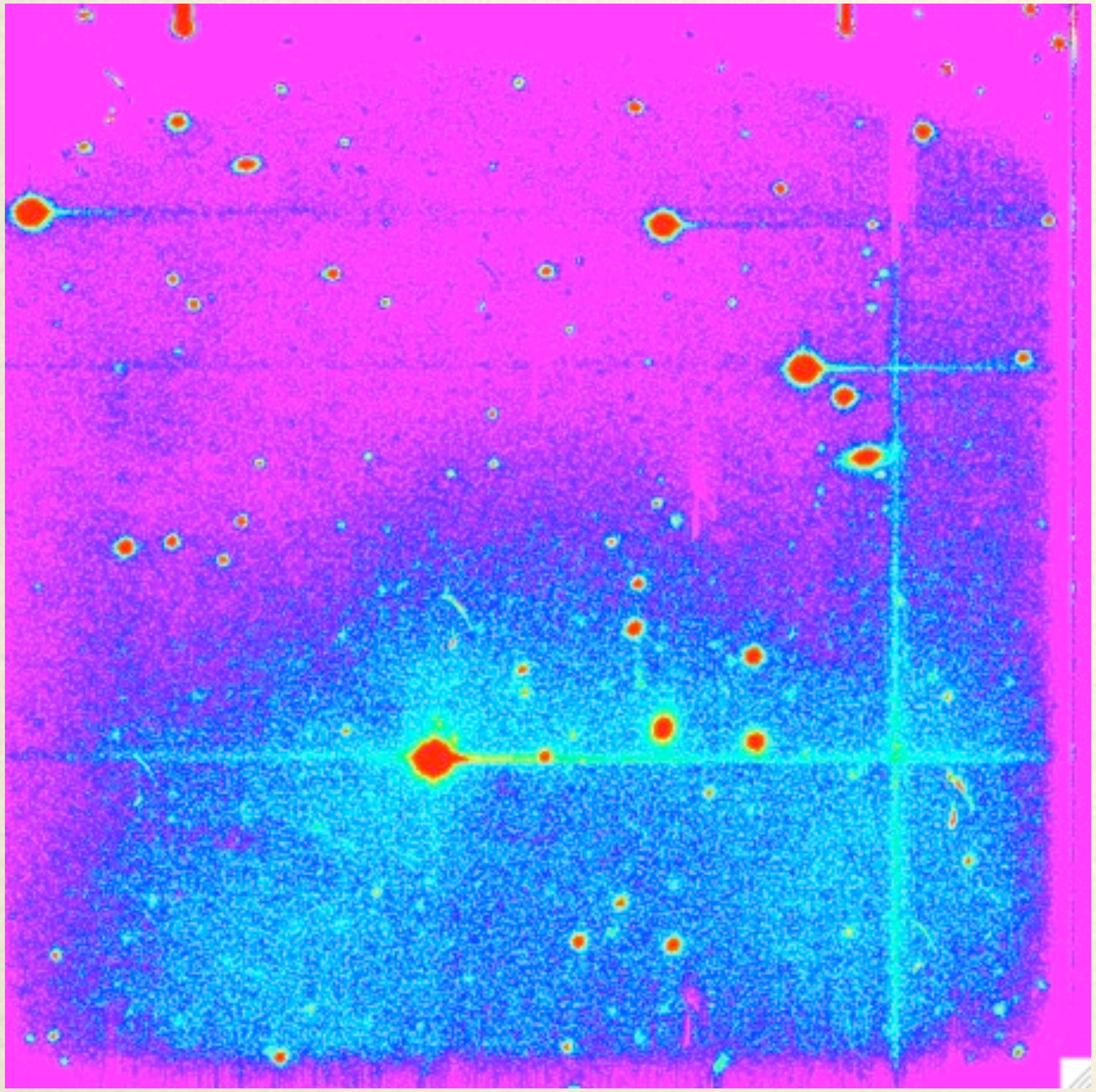
Integral field spectroscopy





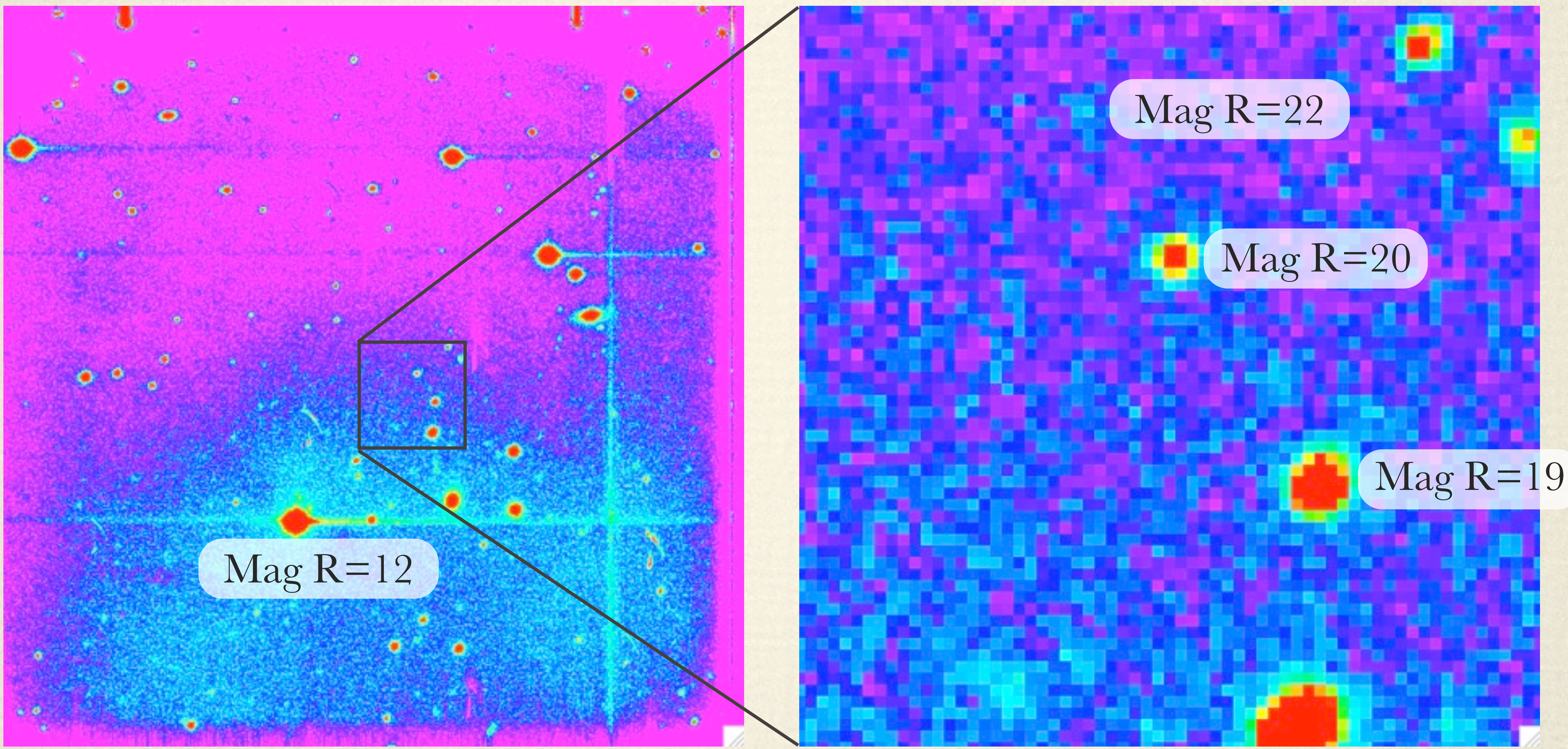
- 48 Fabry-Perot channels (R ≈ 15000)
- 0.5s / image
- 10 images / channel
- 3 hours total

Hα narrow band imaging (30Å)



Sum of ~2 hours at 10 fps - Preliminary results

Hα narrow band imaging (30Å)



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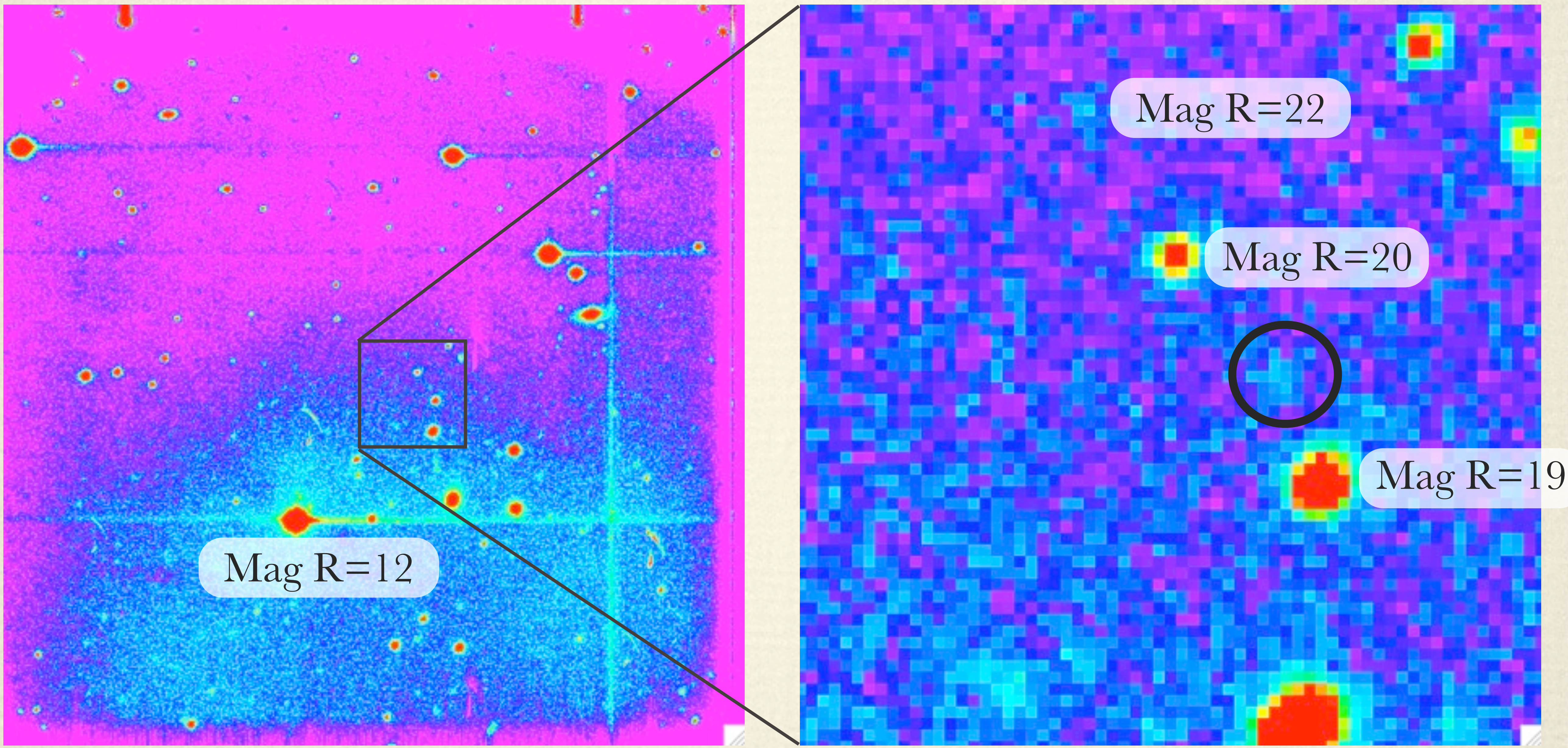

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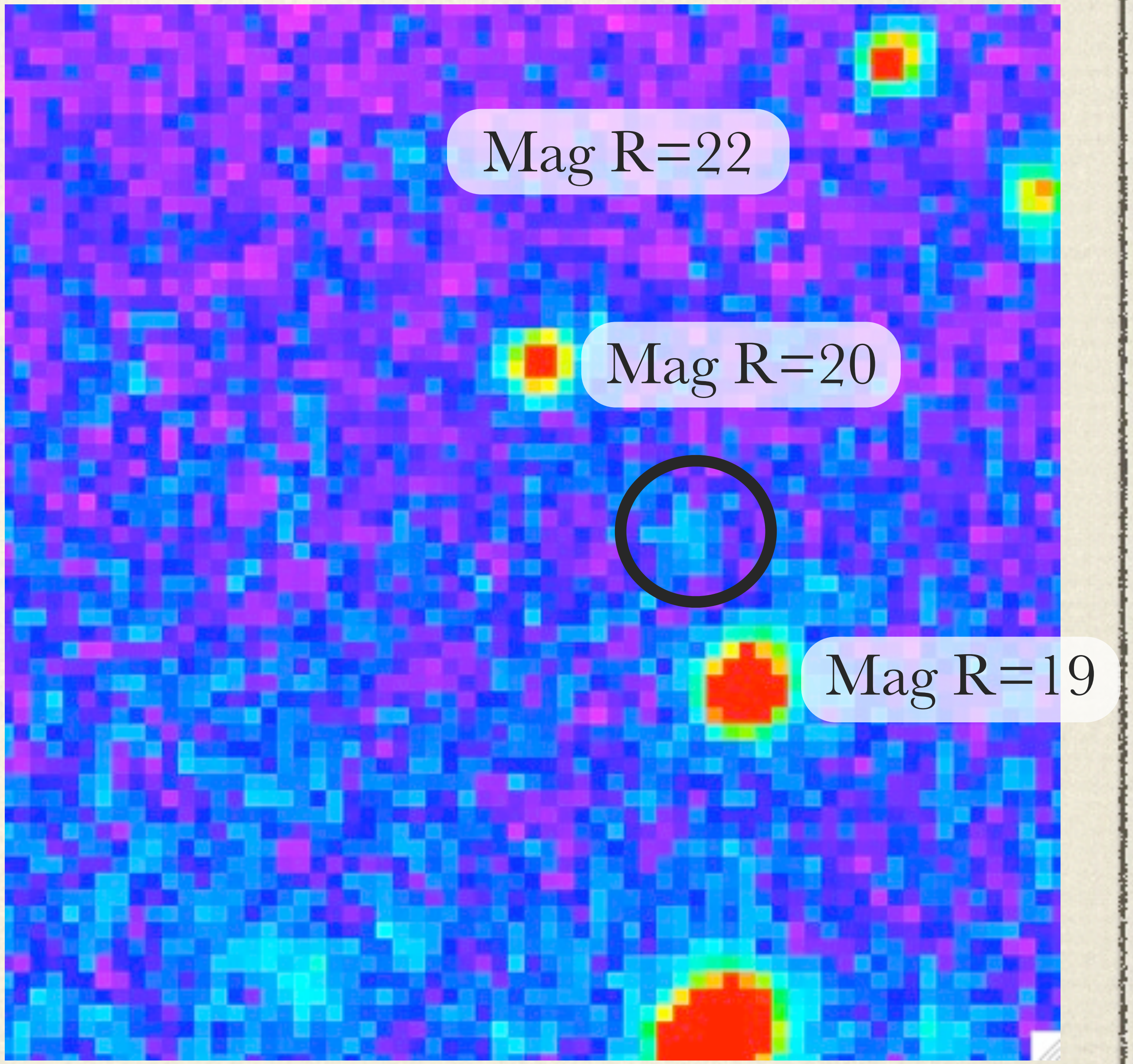
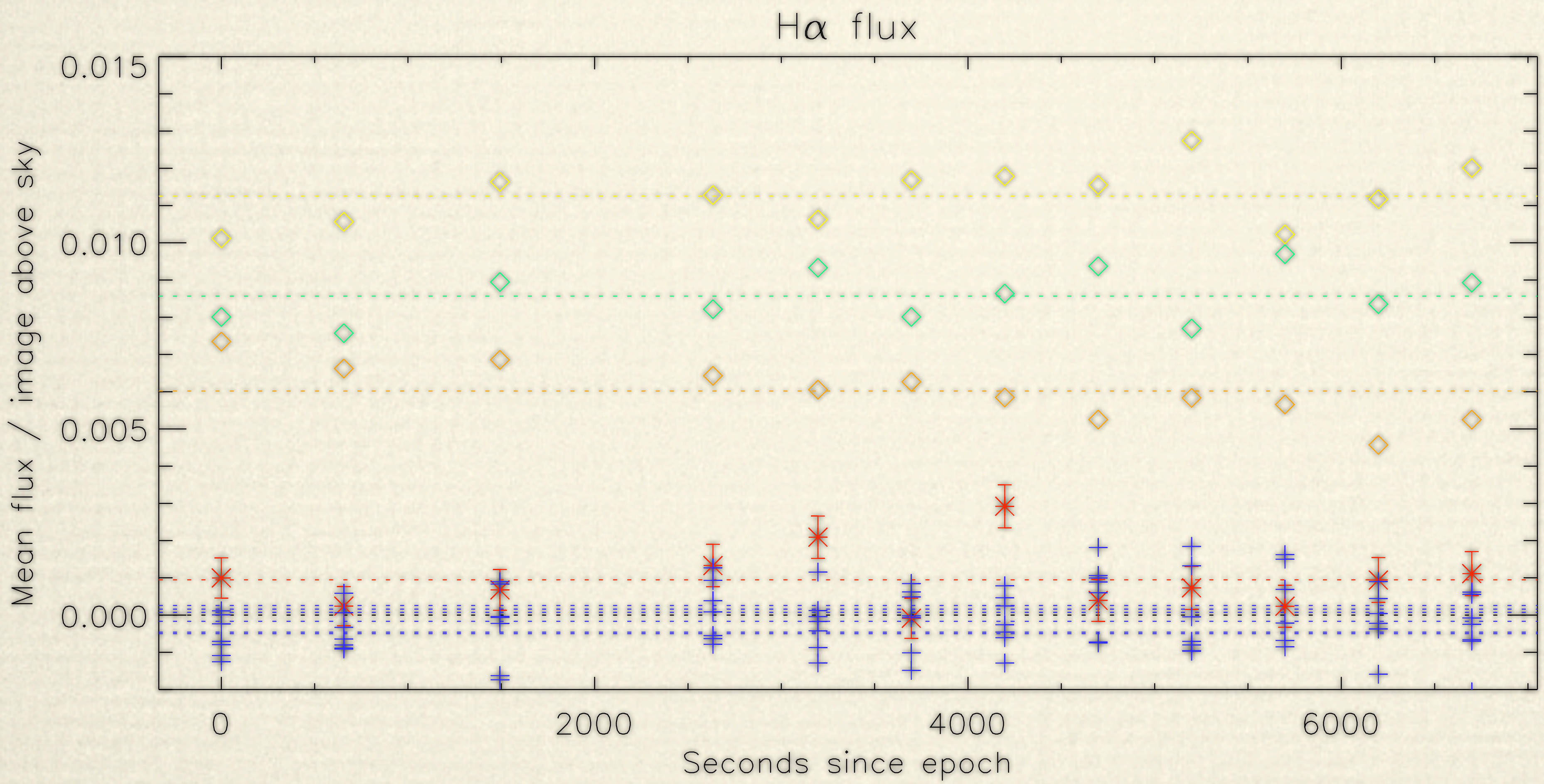
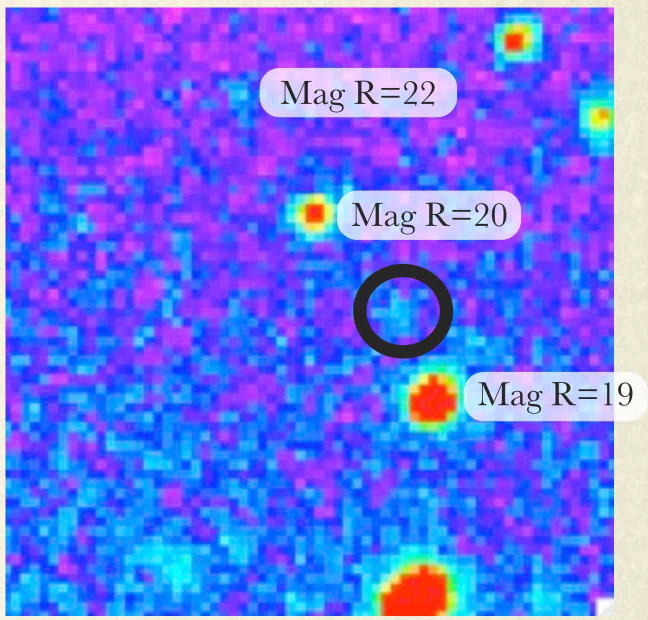


Temporal bins of 10 minutes - Preliminary results

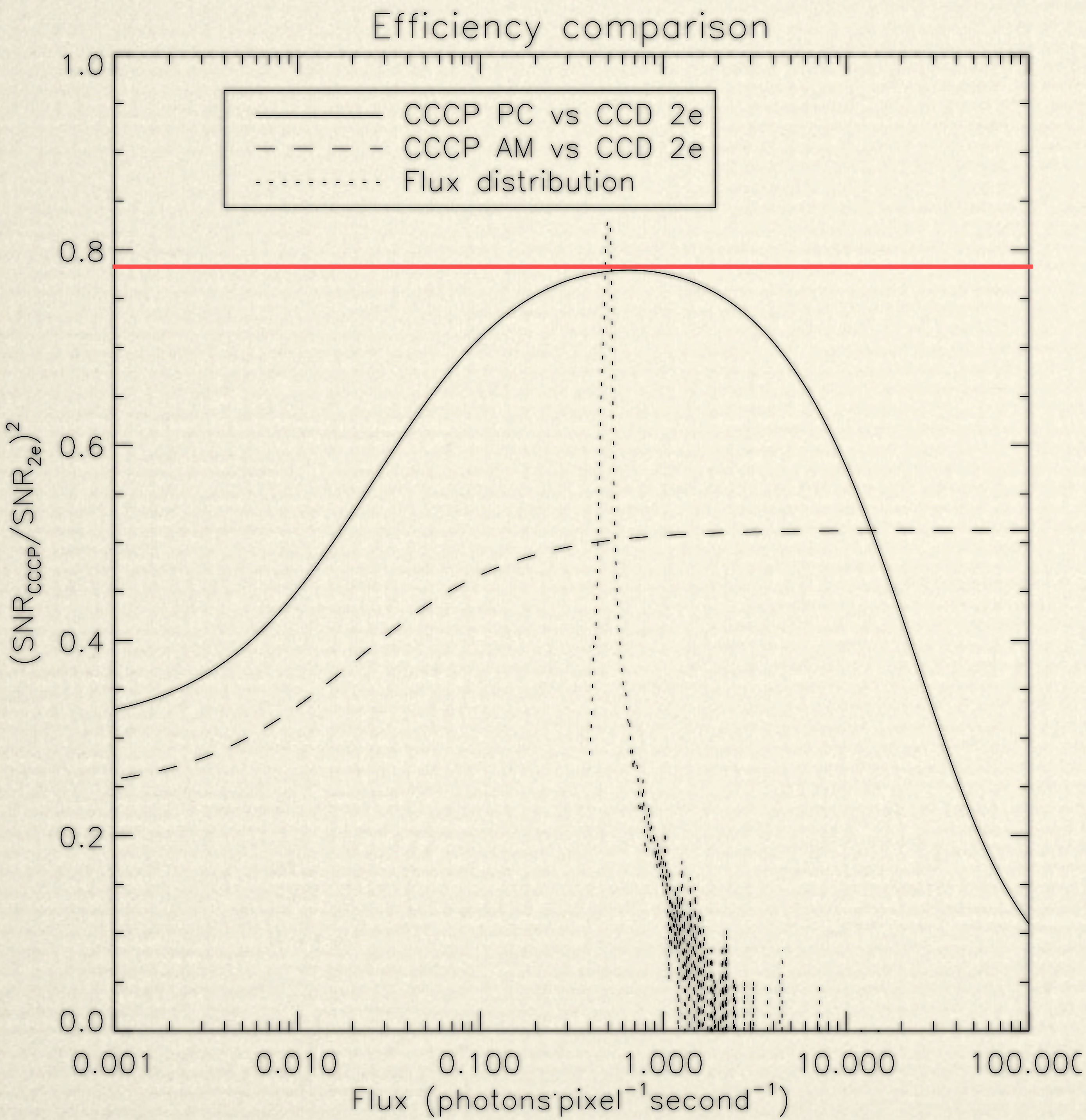
Hα narrow band imaging (30Å)





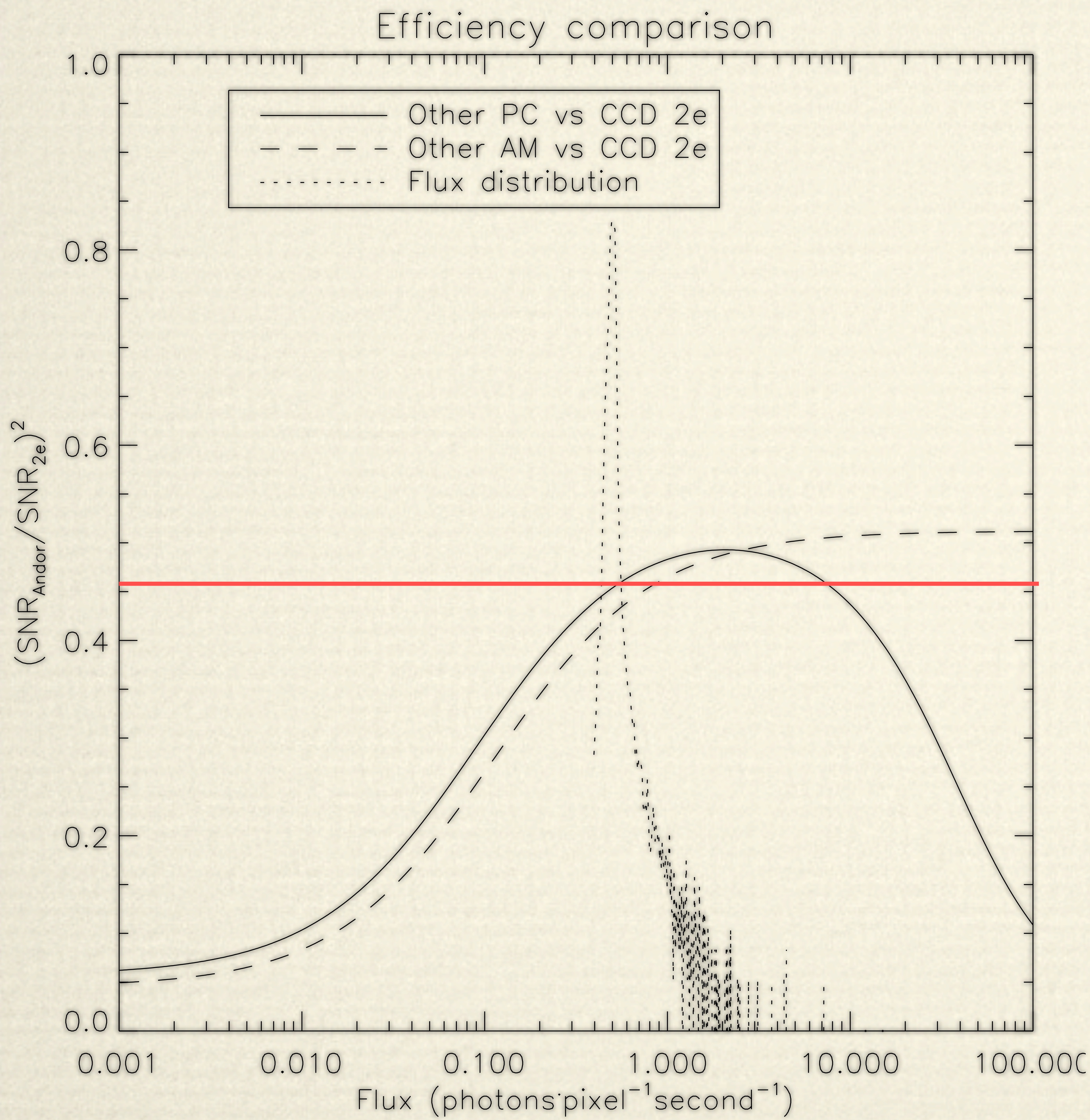
Temporal bins of 10 minutes - Preliminary results

Comparison with low noise CCD



- CCD, σ=2ē
  - 10 minutes / image
  - Dark 0.001 ē/pix/s
- CCD97 w/ CCCP
  - 0.1s / image
  - Dark 0.001 ē/pix/s
  - CIC 0.0023 event/ pix/im

Comparison with low noise CCD



- CCD, σ=2ē
  - 10 minutes / image
  - Dark 0.001 ē/pix/s
- CCD97 w/ Other
  - 0.1s / image
  - Dark 0.001 ē/pix/s
  - CIC 0.008 event/pix/im

Conclusions

- CCCP achieves low CIC levels and high G/σ ratio, even in inverted mode
  - Makes PC operation efficient with an EMCCD
  - Also improves horizontal CTE (not covered)
  - Dark noise limited for $t_{exp} > 5$s
- CIC generated in the horizontal register dominates
  - Tested at 10MHz, can operate faster

Conclusions

- EMCCD noise is still CIC dominated
  - Changes to the design and to the manufacturing processes could lower the CIC impact
  - Should be explored for larger format EMCCDs

Thanks for your attention

Questions?

odaigle@astro.umontreal.ca

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Photon etc.
A spectrum of solutions

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