Overview on Low-flux Detectors

J. Eike von Seggern for the ALPS collaboration

DESY Hamburg

9th Patras Workshop, Schloß Waldthausen, Mainz
Wednesday, 26. June 2013

Max-Planck-Institut
für Gravitationsphysik
(Albert-Einstein-Institut)

Introduction

- Very low noise detectors necessary to find/constrain low flux
- $\mathcal{O}$(few eV) $\Rightarrow$ optics/ext. background easy
  but int. background difficult
- Overlap with QI requirements
- To reduce int. background go to cryogenic temperatures

(Eisamann, et. al: Rev. Sci. Instrum. 82, 071101 (2011))

Introduction

- Very low noise detectors necessary to find/constrain low flux
- $\mathcal{O}$(few eV) $\Rightarrow$ optics/ext. background easy
  but int. background difficult
- Overlap with QI requirements
- To reduce int. background go to cryogenic temperatures

$\Rightarrow$ Expect some options

(Eisamann, et. al: Rev. Sci. Instrum. 82, 071101 (2011))

Introduction

- Very low noise detectors necessary to find/constrain low flux
- $\mathcal{O}$(few eV) $\Rightarrow$ optics/ext. background easy
  but int. background difficult
- Overlap with QI requirements
- To reduce int. background go to cryogenic temperatures

Outline

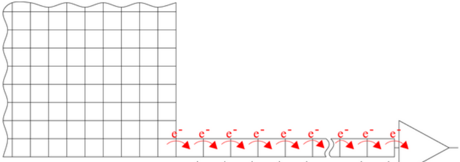
1. CCD
2. Cryogenic detectors
3. PMT
4. Conclusions

(Eisamann, et. al: Rev. Sci. Instrum. 82, 071101 (2011))

Ordinary CCD

- Exemplary: PIXIS CCD used in ALPS-I
- Works out of the box
- Cooled to $-70\,^\circ\mathrm{C}$
  $\Rightarrow$ dark count rate $R_{\mathrm{DN}} = 7.5 \cdot 10^{-4}\ \frac{\mathrm{ADU}}{\mathrm{px\ s}}$
- Slow read-out
  $\Rightarrow$ low RO-noise: $\sigma_{\mathrm{RO}} = 4.2$ ADU
- Low gain: $1.02\ \frac{\mathrm{e}^-}{\mathrm{ADU}}$
- Pixel size: 13 µm
- Sensitivity: $\approx 6 \cdot 10^{-4}\ \frac{\mathrm{photons}}{\mathrm{s\ px}}$ (95 % CL)
  (with 100 h dark and 20 h bright data, 80 % QE (@532 nm))

Faint Flux EMCCD



- EMCCD: Multiply collected charges before RO-register
- Allows to ignore read-out noise
- Gain of EM $\mathcal{O}(1000)$
- Interpret pixel value as binary: photon detected yes/no?

  (problematic for "high" fluxes: coincidences, CIC)
- "Count" photon if output signal $> k\sigma$
- Sensitivity: $\approx 2.8 \cdot 10^{-4}\ \frac{\text{photons}}{\text{s px}}$ (95 % CL)

  (with 20 h bright data, 80 % QE (@532 nm), $R_{\text{DN}} = 7.5 \cdot 10^{-4}\ \frac{\text{ADU}}{\text{s px}}$)

One cannot beat dark noise!
$\rightarrow$ Cryogenic temperatures

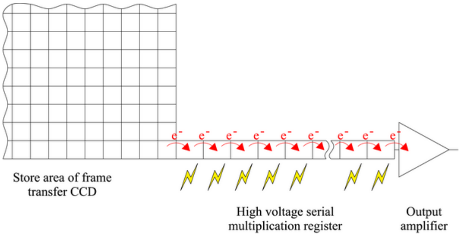
(Daigle, *et.al.*: [0908.0528])

Faint Flux EMCCD

- EMCCD: Multiply collected charges before RO-register
- Allows to ignore read-out noise
- Gain of EM $\mathcal{O}(1000)$
- Interpret pixel value as binary: photon detected yes/no?

  (problematic for "high" fluxes: coincidences, CIC)
- "Count" photon if output signal $> k\sigma$
- Sensitivity: $\approx 2.8 \cdot 10^{-4} \, \frac{\text{photons}}{\text{s px}}$ (95 % CL)

  (with 20 h bright data, 80 % QE (@532 nm), $R_{\text{DN}} = 7.5 \cdot 10^{-4} \, \frac{\text{ADU}}{\text{s px}}$)

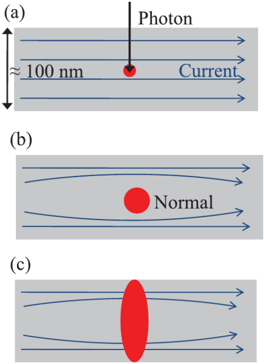


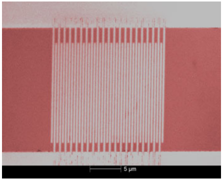
One cannot beat dark noise!
→ Cryogenic temperatures

(Daigle, *et.al.*: [0908.0528])

Superconducting Nanowire single-photon detector (SNSPD)

- SC nano wire with bias current just below j_{crit}
- Absorbed photon creates normal conducting region
- Flux is expelled $\Rightarrow$ flux density $> j_{\text{crit}}$
- Operating temperature $\lesssim 4\,\text{K}$
- Meandering layout to create sensitive area $\mathcal{O}(10 \times 10\ \mu\text{m}^2)$
- Optical cavity to increase absorption efficiency
- Achieved efficiency $\sim 60\,\%$ @NIR
- But dark count rate $> 0.1\ \frac{\text{cnt}}{\text{s}}$ (Shen,Yang,Lou 2010)





TES

- Bolometric detector:
  photon absorption $\rightarrow$ temp. rise $\rightarrow$ signal
- Cryogenic read out: SQUID
- Couple signal into fiber
- High QE (almost 100 %) for target wavelength
- Very low noise $\sim 10^{-3}\ \frac{\text{cnt}}{\text{s}}$
  (hopefully $<\sim 10^{-5}\ \frac{\text{cnt}}{\text{s}}$)
- Sensitivity: $\approx 6.0 \cdot 10^{-5}\ \frac{\text{photons}}{\text{s px}}$ (95 % CL)

TES

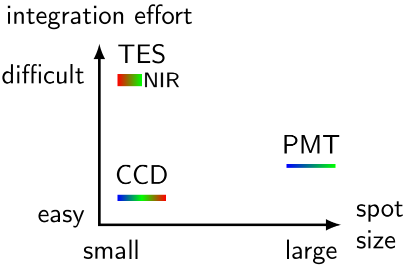
- Bolometric detector:
  photon absorption $\rightarrow$ temp. rise $\rightarrow$ signal
- Cryogenic read out: SQUID
- Couple signal into fiber
- High QE (almost 100 %) for target wavelength
- Very low noise $\sim 10^{-3}\ \frac{\text{cnt}}{\text{s}}$
  (hopefully $<\sim 10^{-5}\ \frac{\text{cnt}}{\text{s}}$)
- Sensitivity: $\approx 6.0 \cdot 10^{-5}\ \frac{\text{photons}}{\text{s px}}$ (95 % CL)

For more details cf. talks by G. Cantatore & J. Dreyling-Eschweiler

PMT

- Large sensitive area
- Limited spectral range: 300–650 nm
- Limited QE: $\lesssim 30\,\%$
- Low dark count rate, e.g. $\sim 0.5\ \frac{\text{cnt}}{\text{s}}$ for $2.5\,\text{cm}^2$ sens. area
  $\Rightarrow$ very good $R_{\text{DN}}/A_{\text{sens}}$
- Sensitivity: $\approx 1.7 \cdot 10^{-2}\ \frac{\text{photons}}{\text{s px}}$ (95 % CL)
- Superior to CCDs when signal cannot be focused on a few pixels

Conclusion



- Less options than I expected!
- Many devices still noisy (SNSPD, ...)
- Small spots:
  - CCD: easy but noisy
  - If you have the resources: Go for a TES!
- Large spots: PMT