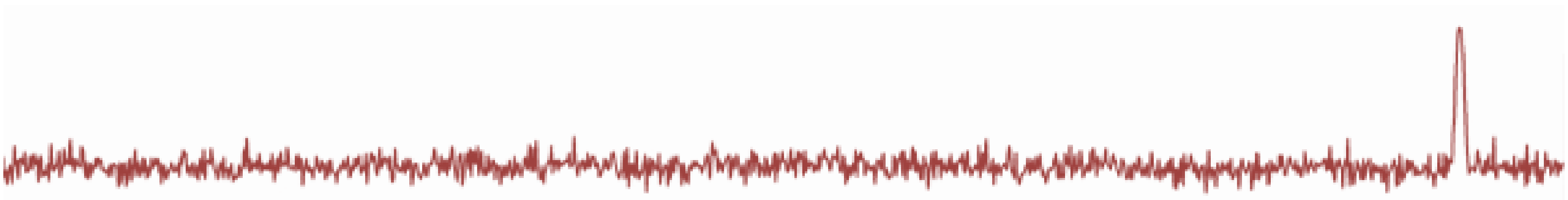
Graphene devices with superconducting contacts for terahertz photon detection



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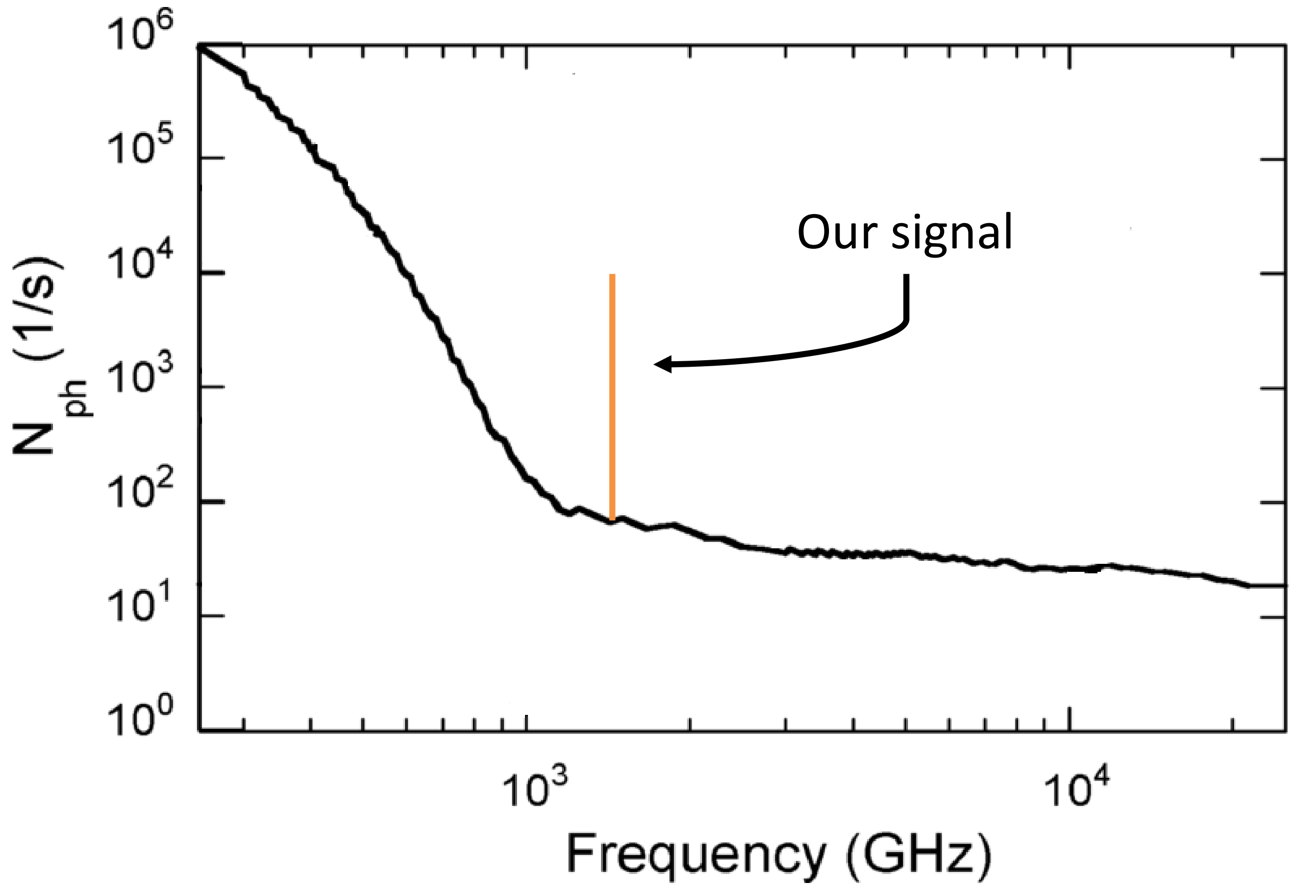
Terahertz photon detector

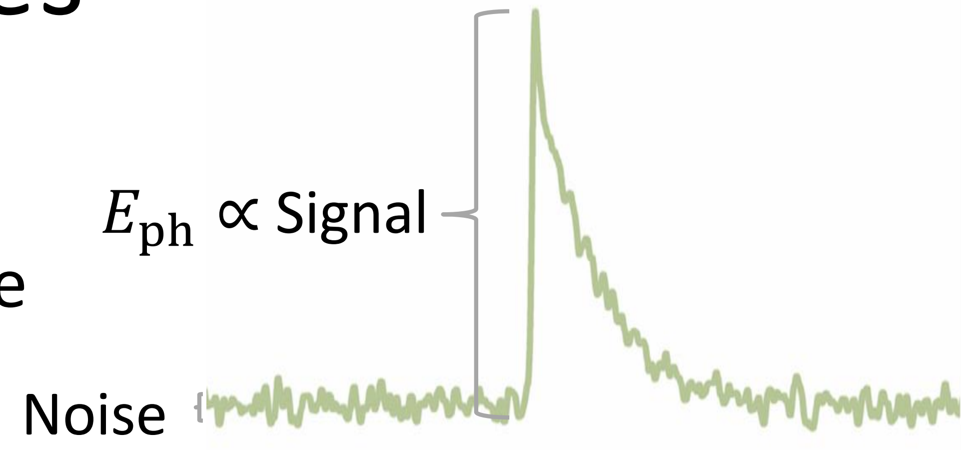


Background Photon Arrival Rate
(Outer Space)

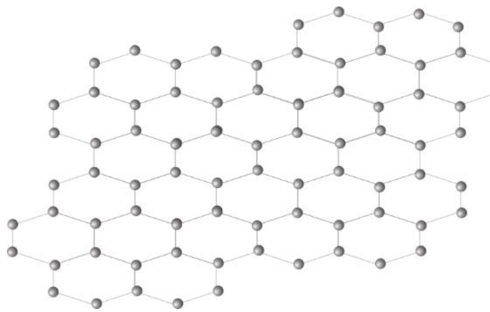
B. S. Karasik, and A. V. Sergeez, *IEEE Transactions on Applied Superconductivity* **15**, 618–621 (2005).

Desired properties

- Linear response
- Sensitive: Signal ≫ Noise



Why graphene?



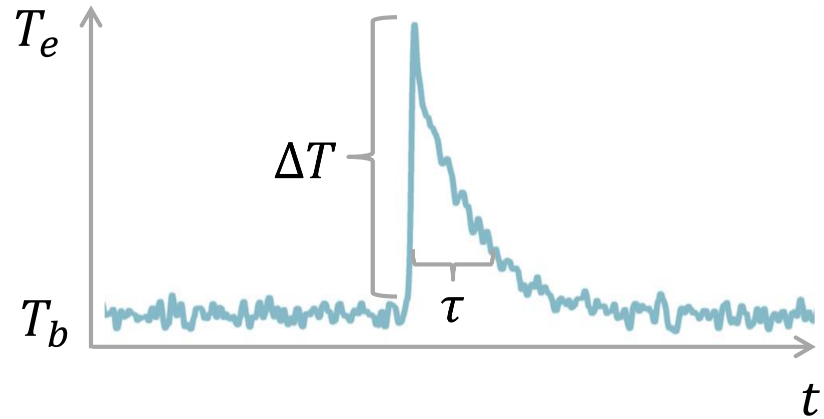
Few electrons

- Very low heat capacity
- Single-photon sensitivity

$$\delta E_{\text{intrinsic}} = \sqrt{\mathrm{k_B} {T_b}^2 C}$$

Image from http://commons.wikimedia.org/wiki/File:Graphene_Crystall.PNG

Potential issues



- $R \approx T$-independent

  → Use Johnson noise emission (GHz): $P_J = k_B B T_e$

$$\delta T_{\mathrm{readout}} = \frac{(T_{\mathrm{amp}} + T_b)}{\sqrt{B\tau}}$$

$$\Delta T = E_{\mathrm{ph}}/C$$

(for linear device)

- Electrons may cool off too fast
  - Electron out-diffusion ($G_{\mathrm{diffusion}}$)
  - Electron-phonon coupling (G_{ep})
  - Photon emission (G_{photon})

Potential issues

Low heat capacity—too low?

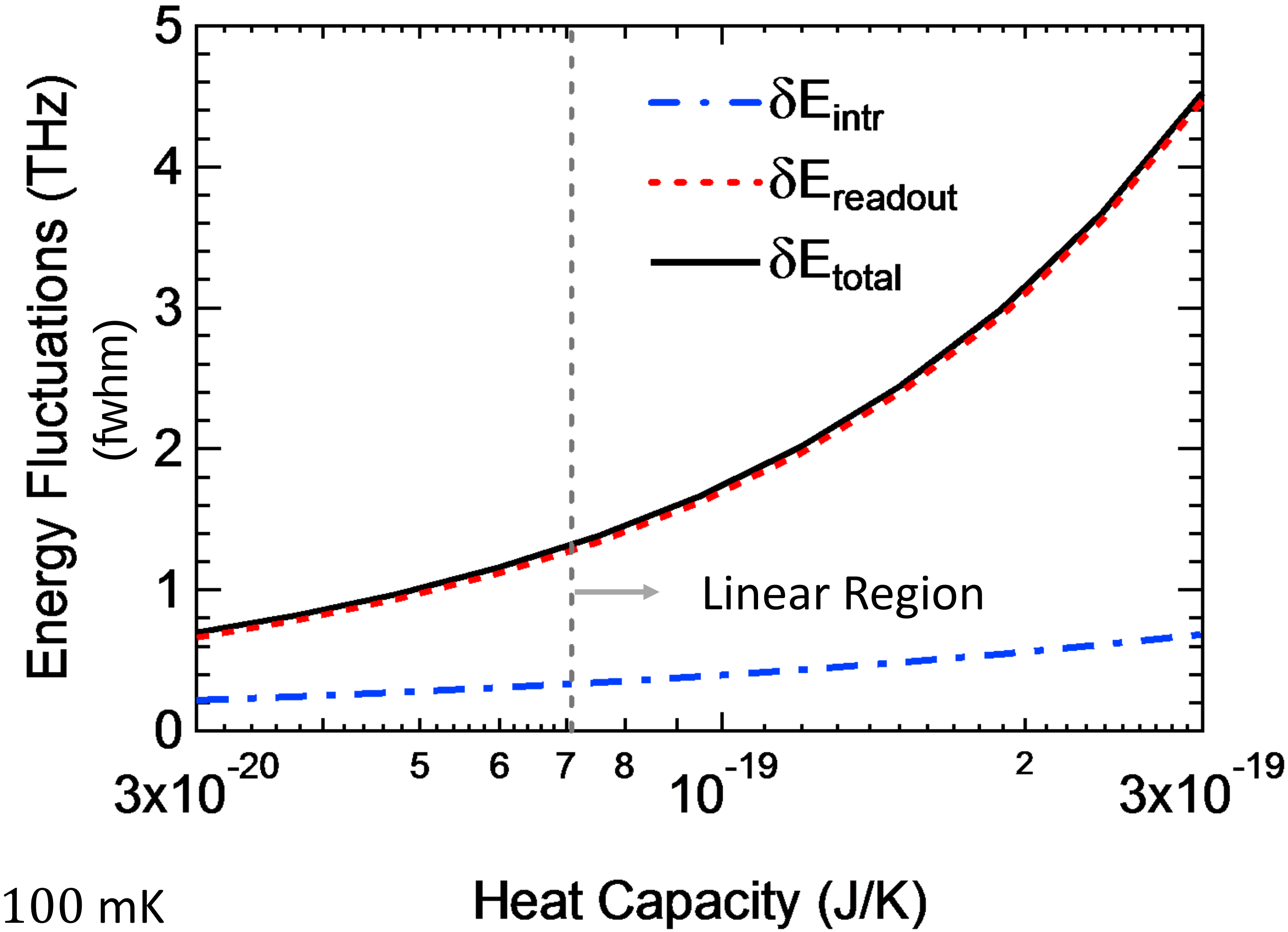
- Want to minimize C for δE, but may lead to $\Delta T \gg T_{\mathrm{b}}$
- Detector might be *too* fast ($\tau = C/G$)

Reason for optimism:

- G_{ep} is predicted to be very small
  - → Manageable (long) response time

$$\delta T_{\mathrm{readout}} = \frac{\left(T_{\mathrm{amp}} + T_b\right)}{\sqrt{B\tau}}$$

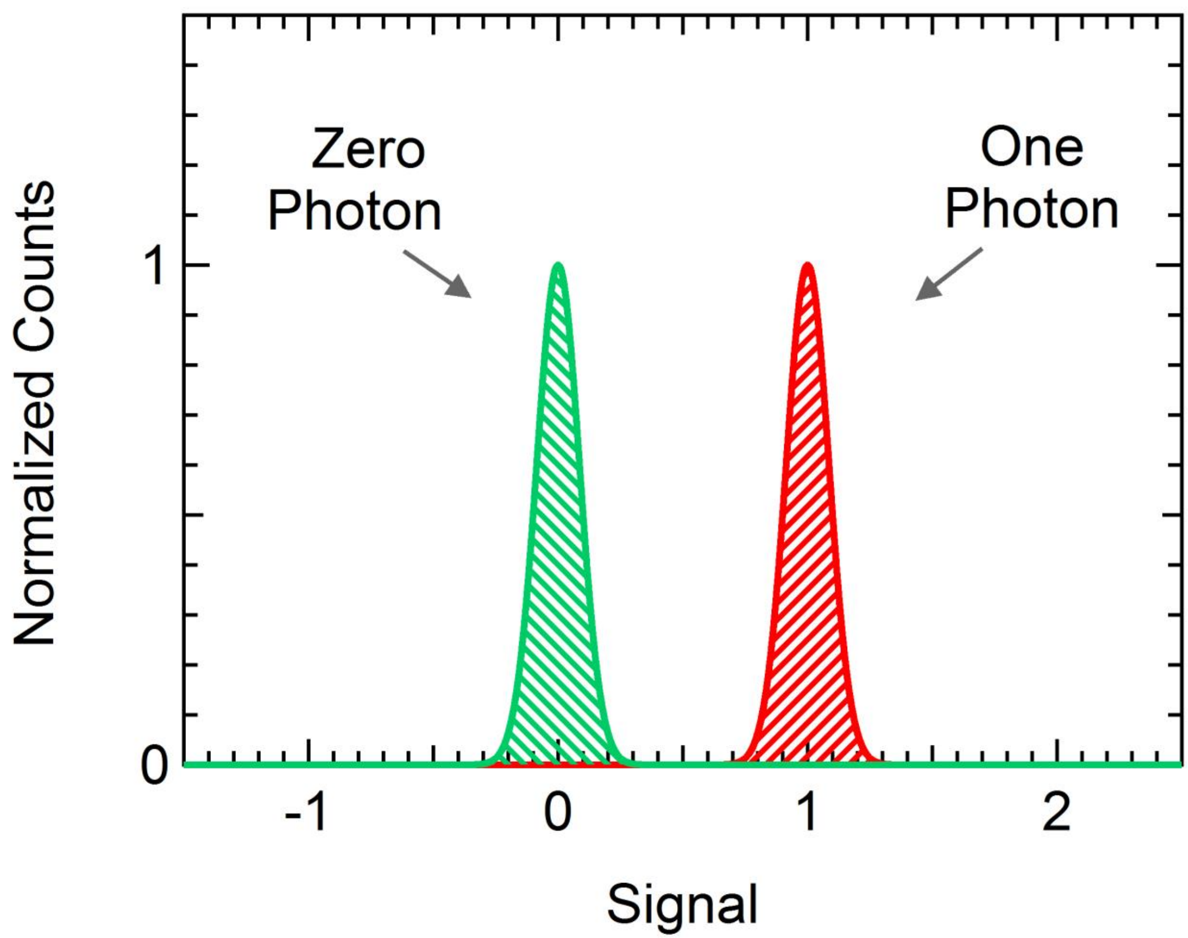
Graphene as a photon detector



$T_{\mathrm{b}} = 100$ mK

Graphene as a photon detector

$E_{\mathrm{ph}}/\delta E = 5$



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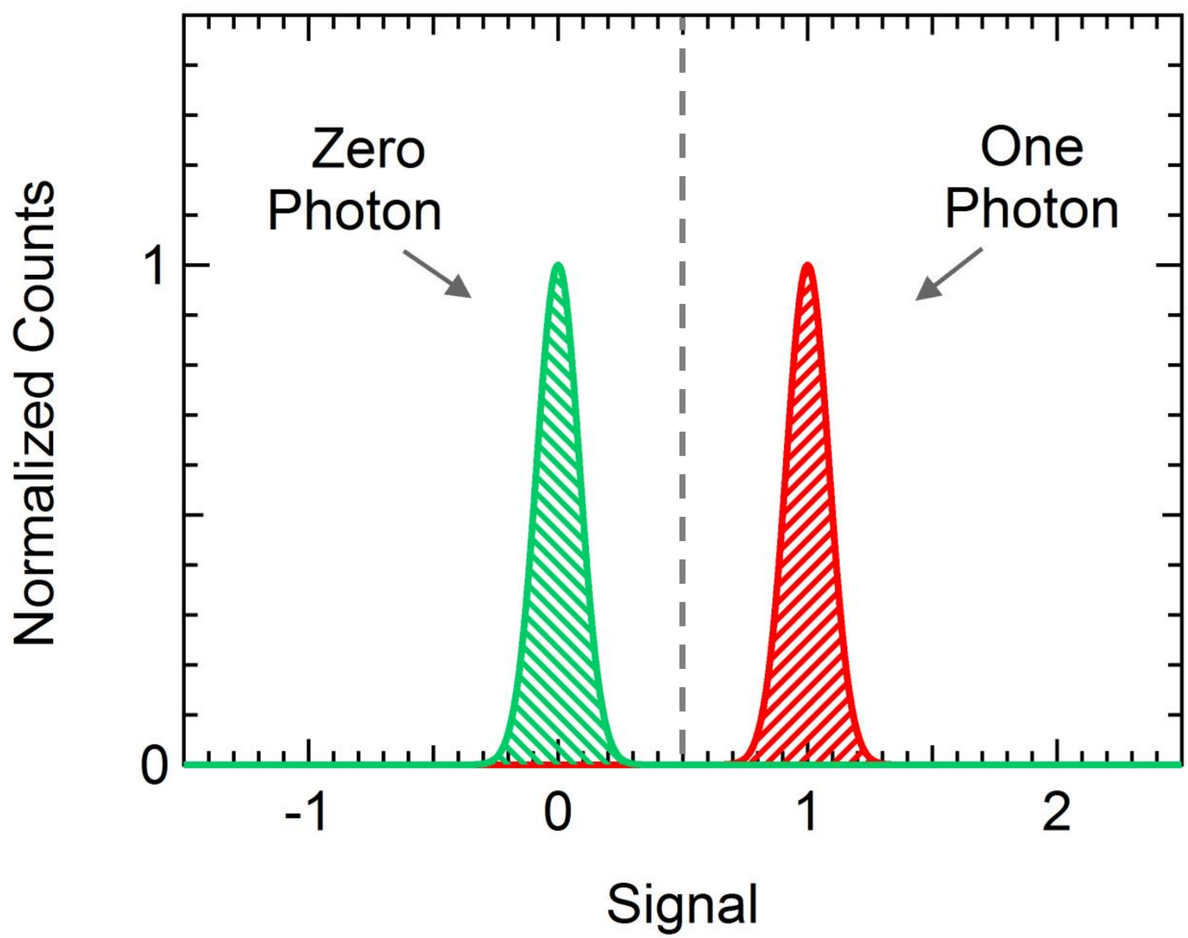
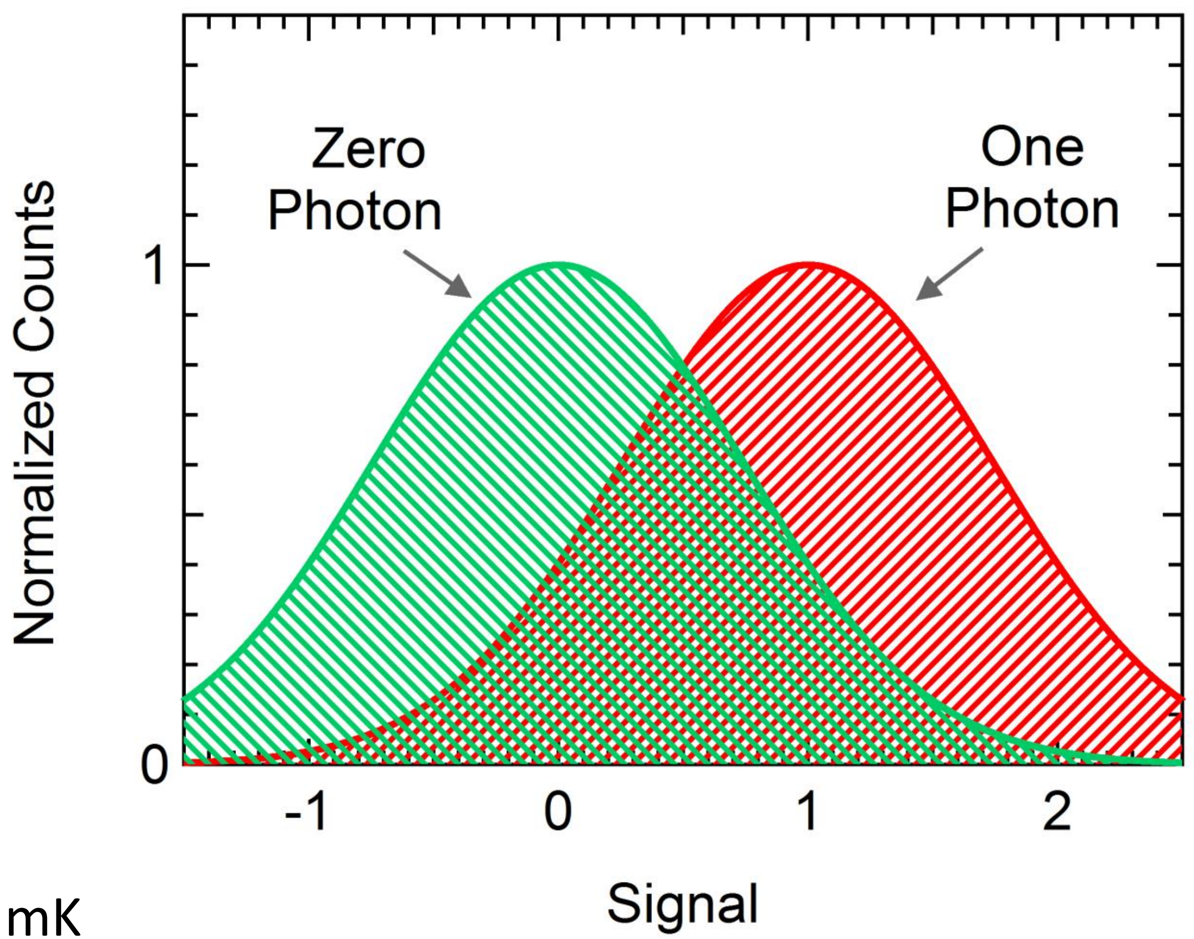


Graphene as a photon detector

$C \approx 1 \times 10^{-19}$ J/K $\Rightarrow$ $E_{\mathrm{ph}}/\delta E = 0.6$



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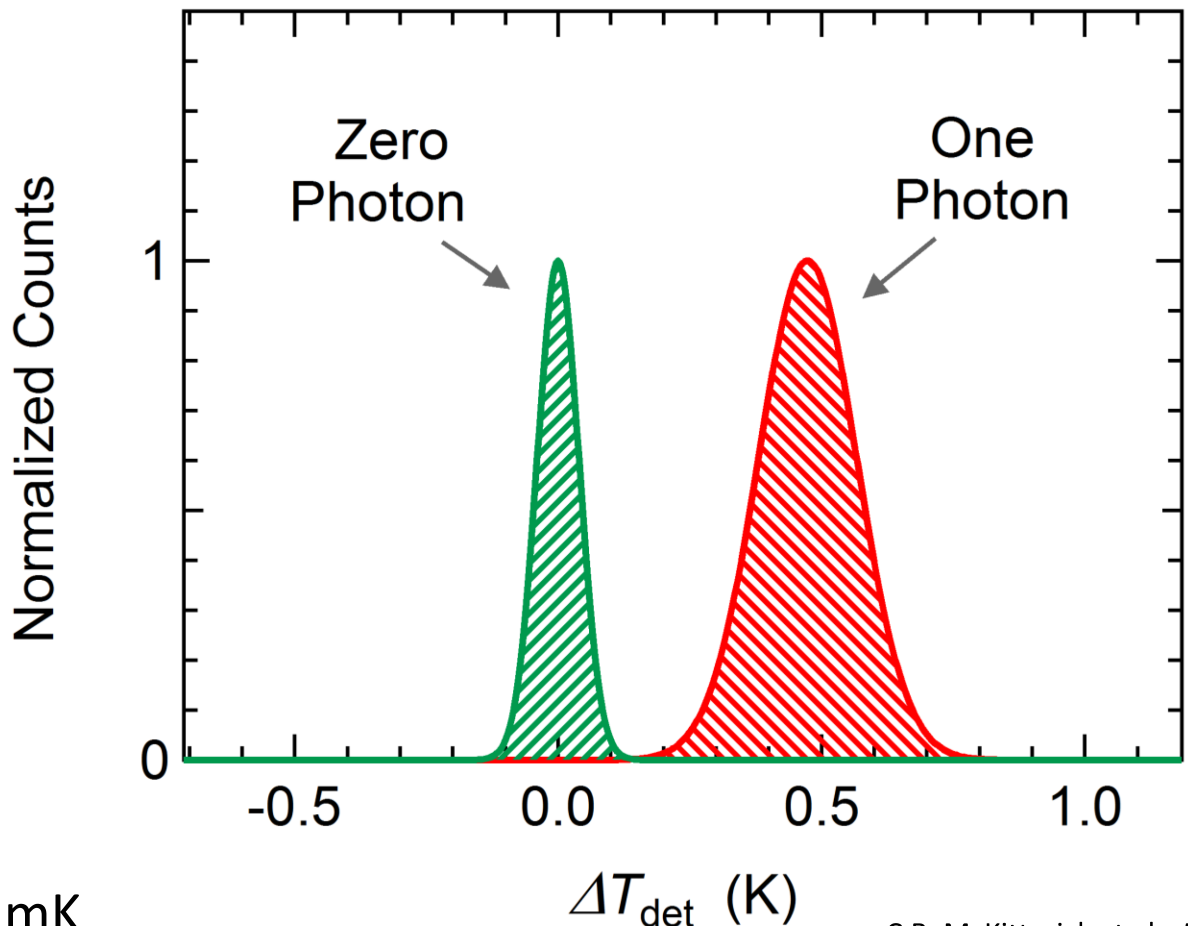
Graphene as a photon detector

$C = 2 \times 10^{-22}$ J/K $\Rightarrow$ far from equilibrium



$T_{\mathrm{b}} = 100$ mK

C.B. McKitterick et al., *J. Appl. Phys.* **113** 044512 (2013)

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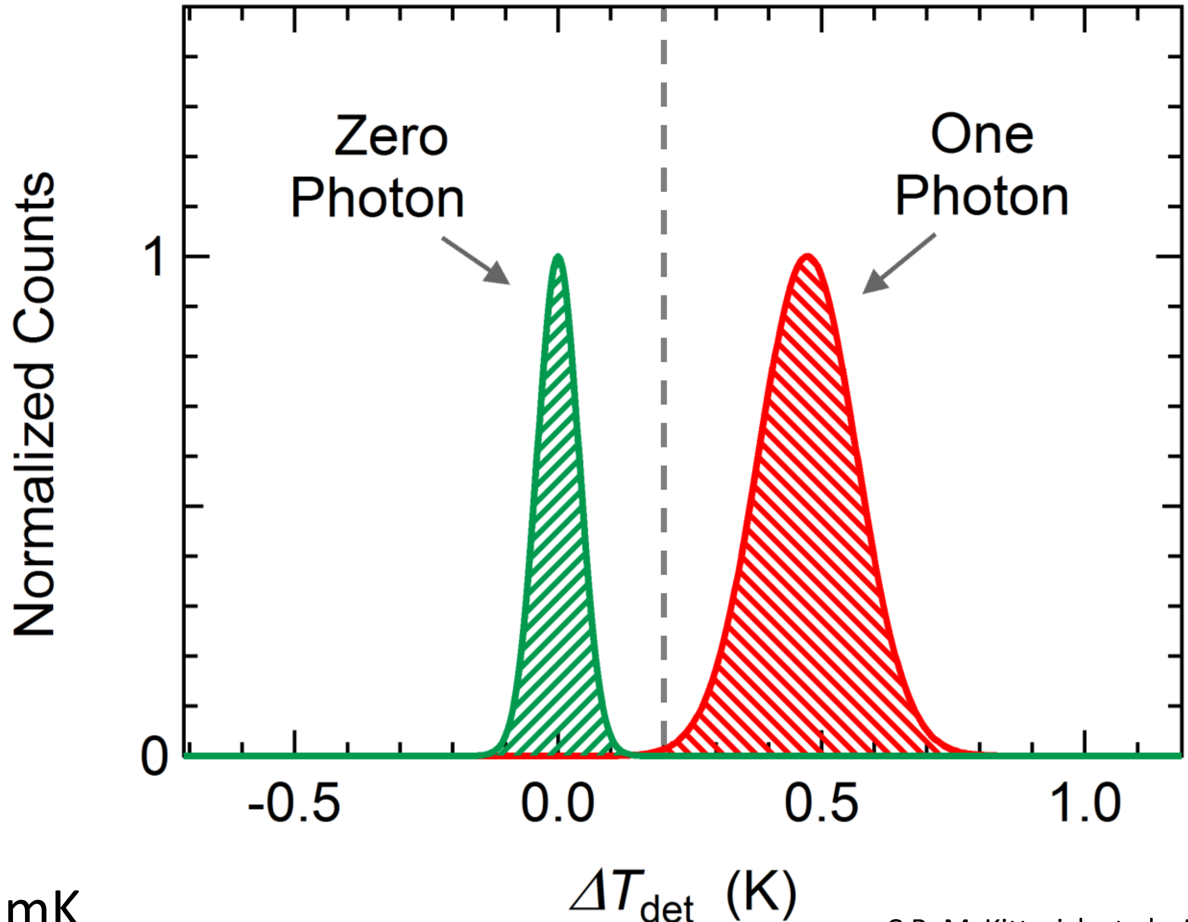

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C.B. McKitterick et al., *J. Appl. Phys.* **113** 044512 (2013)

Graphene detector summary

- Sensitive to single THz photons

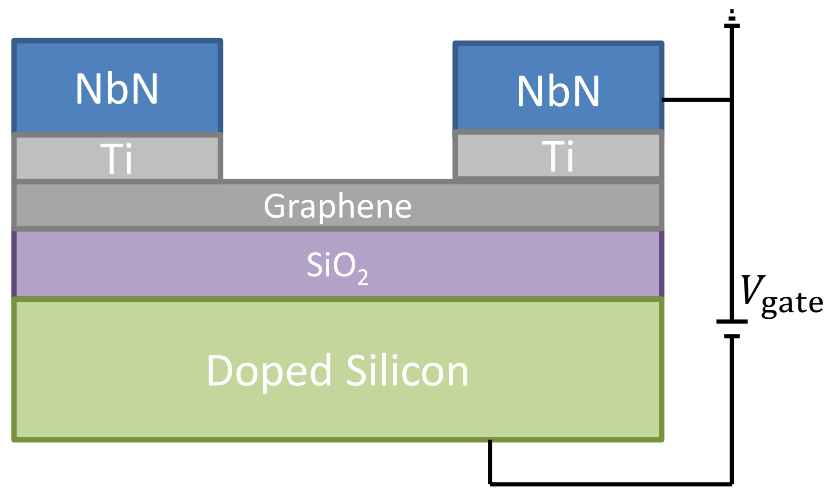
- δE too large for spectroscopy

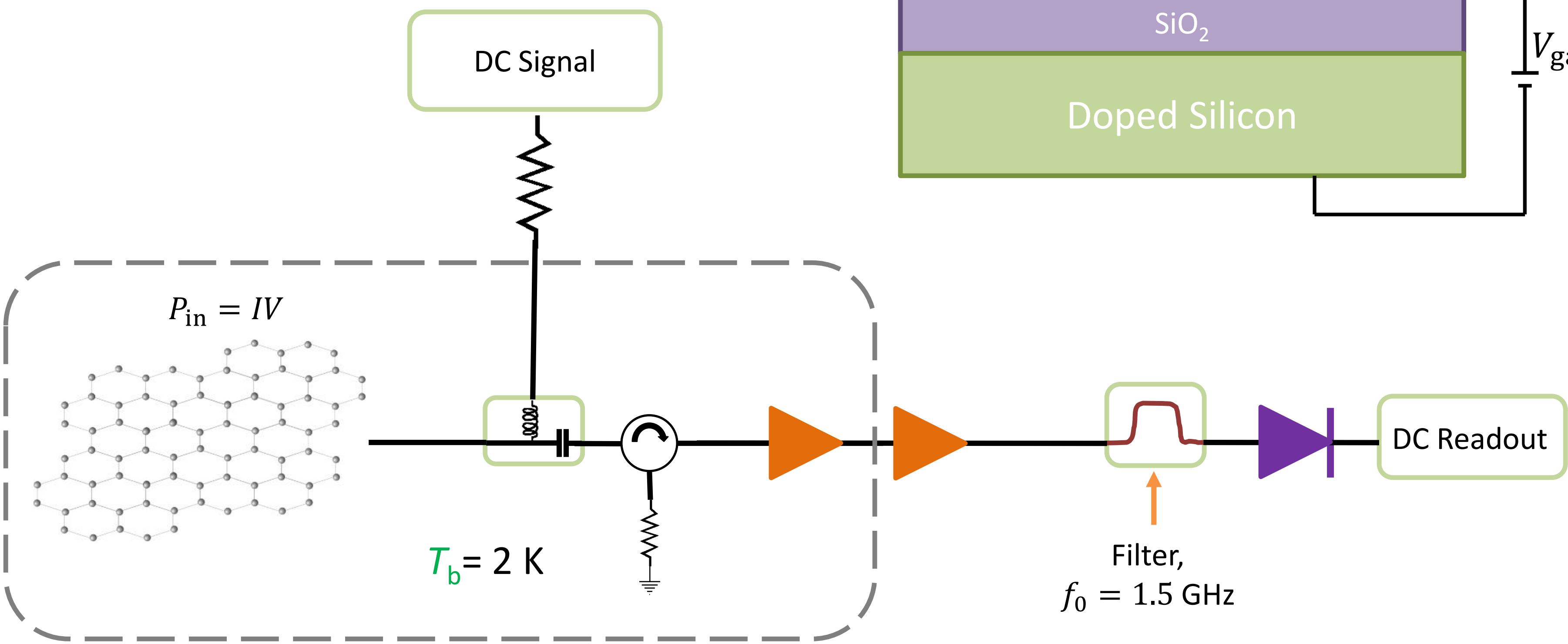
- Depends on unresolved physical parameters (thermal conductivity)[1,2]

[1]A.C. Betz et al., *Phys. Rev. Lett.* **109**, 056805 (2012).

[2]K.C. Fong and K.C. Schwab, *Phys. Rev. X* **2** 031006 (2012)

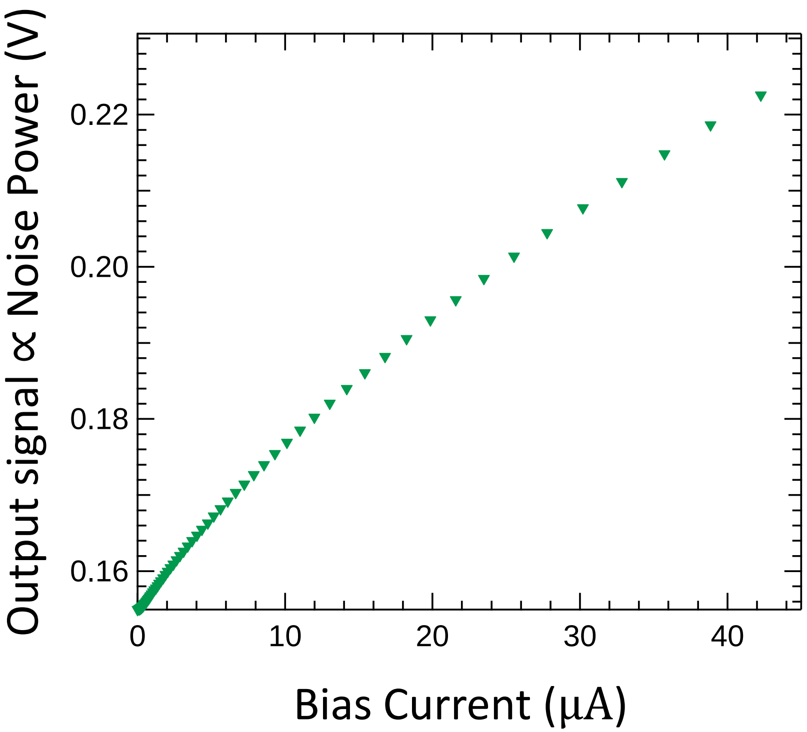
Noise measurements

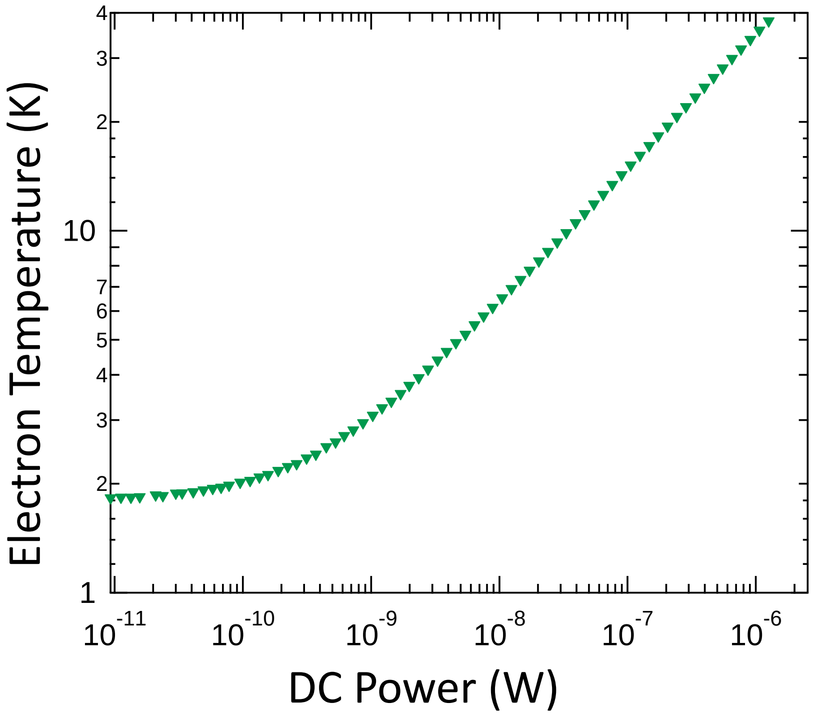




Measured results

- Output is DC voltage proportional to RF Power
- Measure coupling to convert to electron temperature

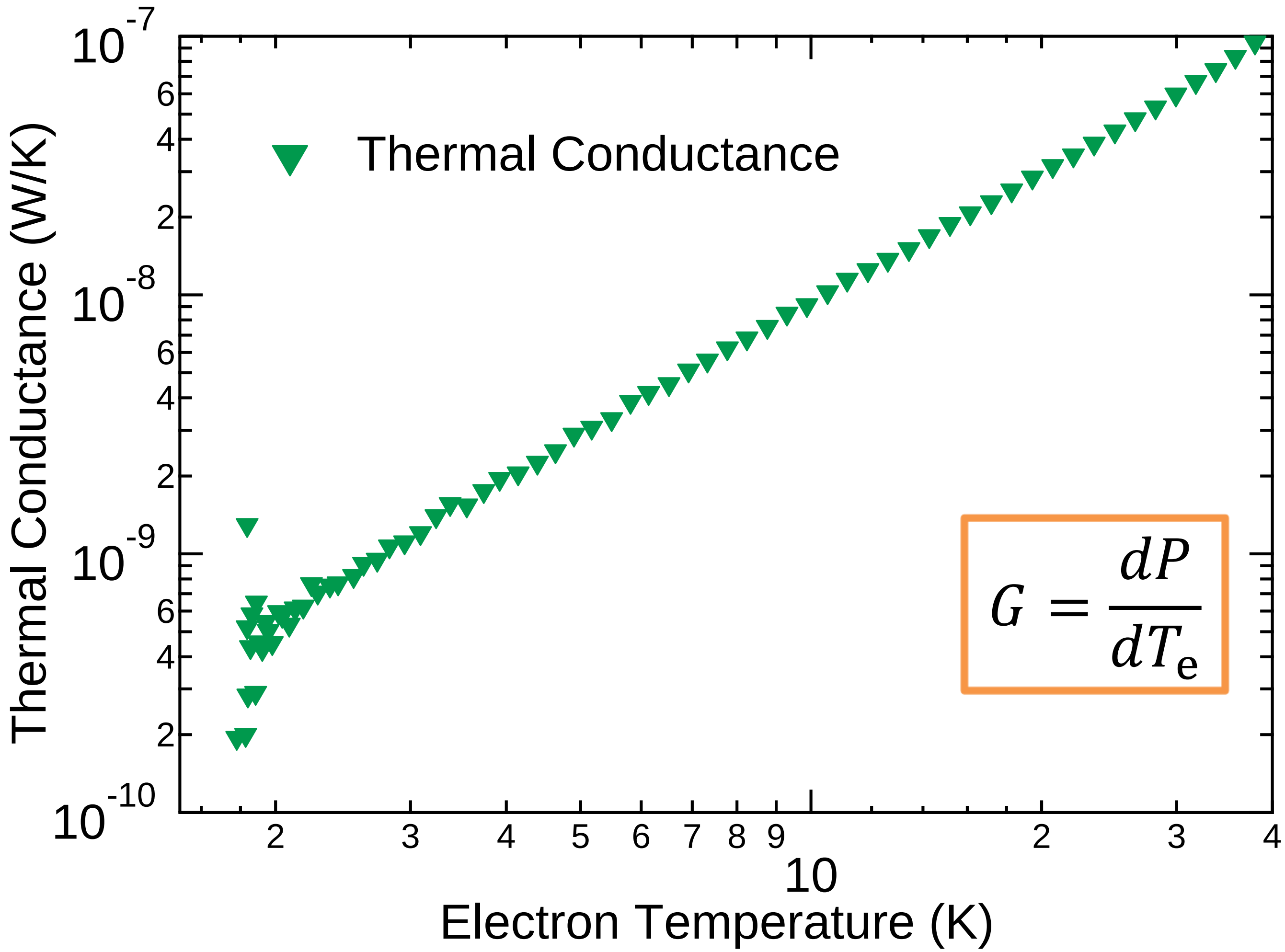




Noise measurements

$G = G_{\text{diffusion}} + G_{\text{ep}} + G_{\text{photon}}$

Desire $G \sim 10^{-15}$ W/K @ 100 mK



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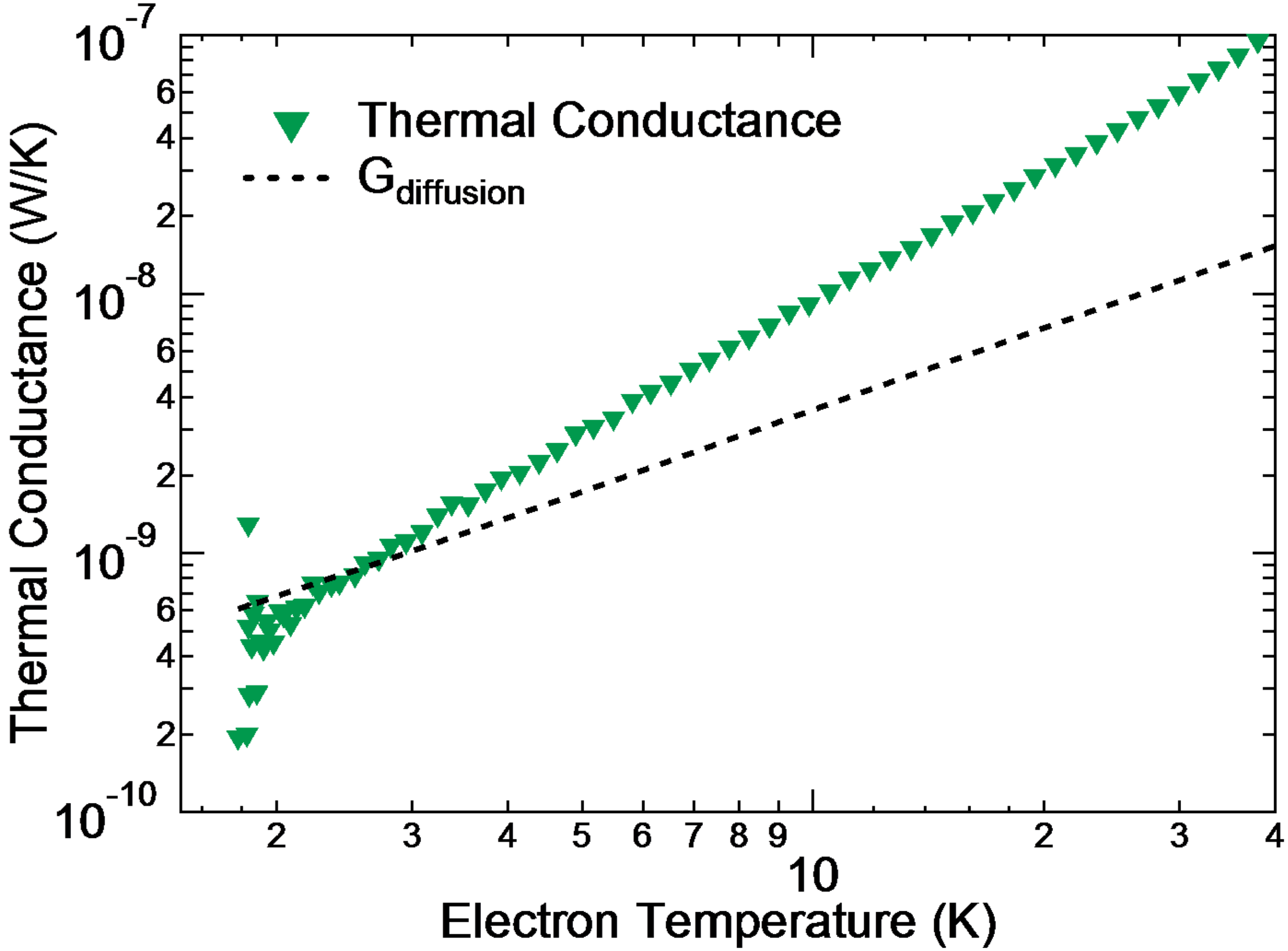

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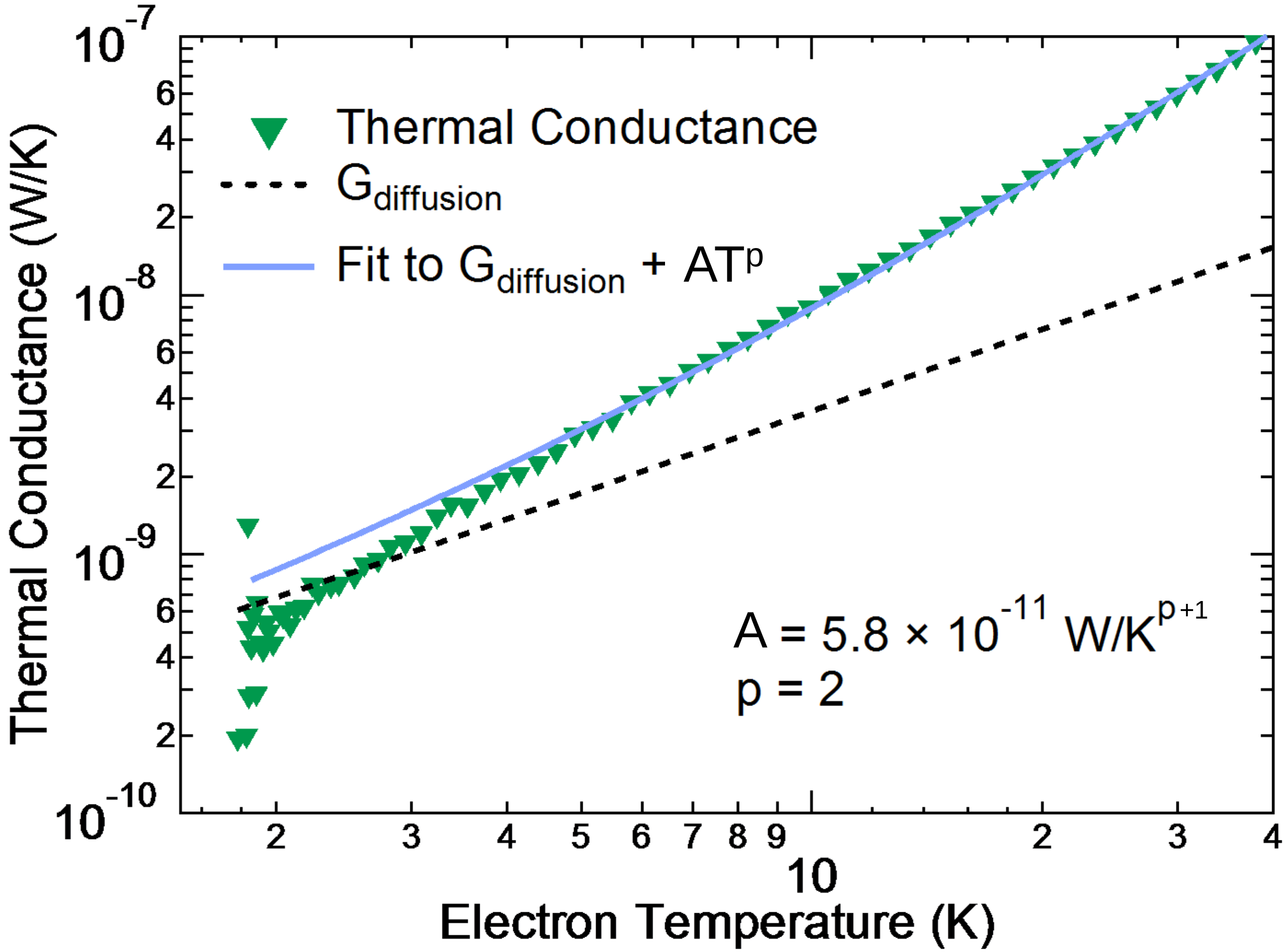
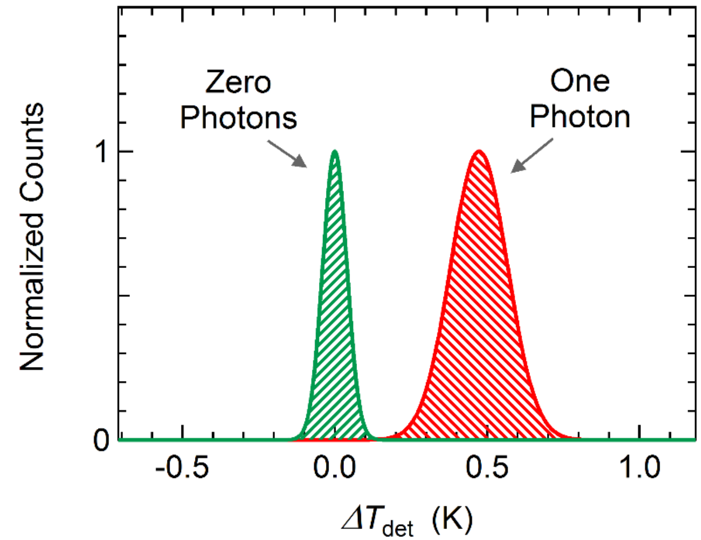
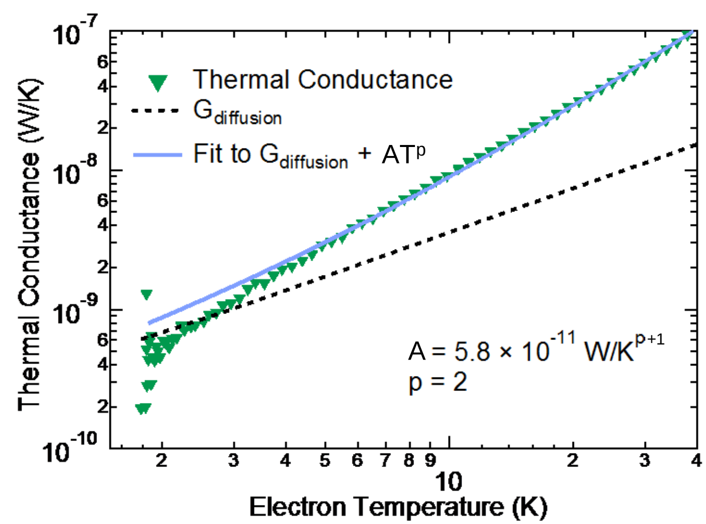


Conclusions

- Graphene has promise as a photon counter, but low energy resolution
- Known unknowns:
  - Initial energy equilibration after absorption
  - Energy confinement



- High T thermal conductance well-described by $G \propto T^2$, electron-phonon?
- Preliminary evidence of electron confinement due to superconducting contacts



Outlook

- Perform measurements at <1 K
- Perform similar measurements on different substrates
- Use interferometer/fiber optics to test graphene bolometers in mid to far-IR