Viper-Informed Infrared Vision Sensing

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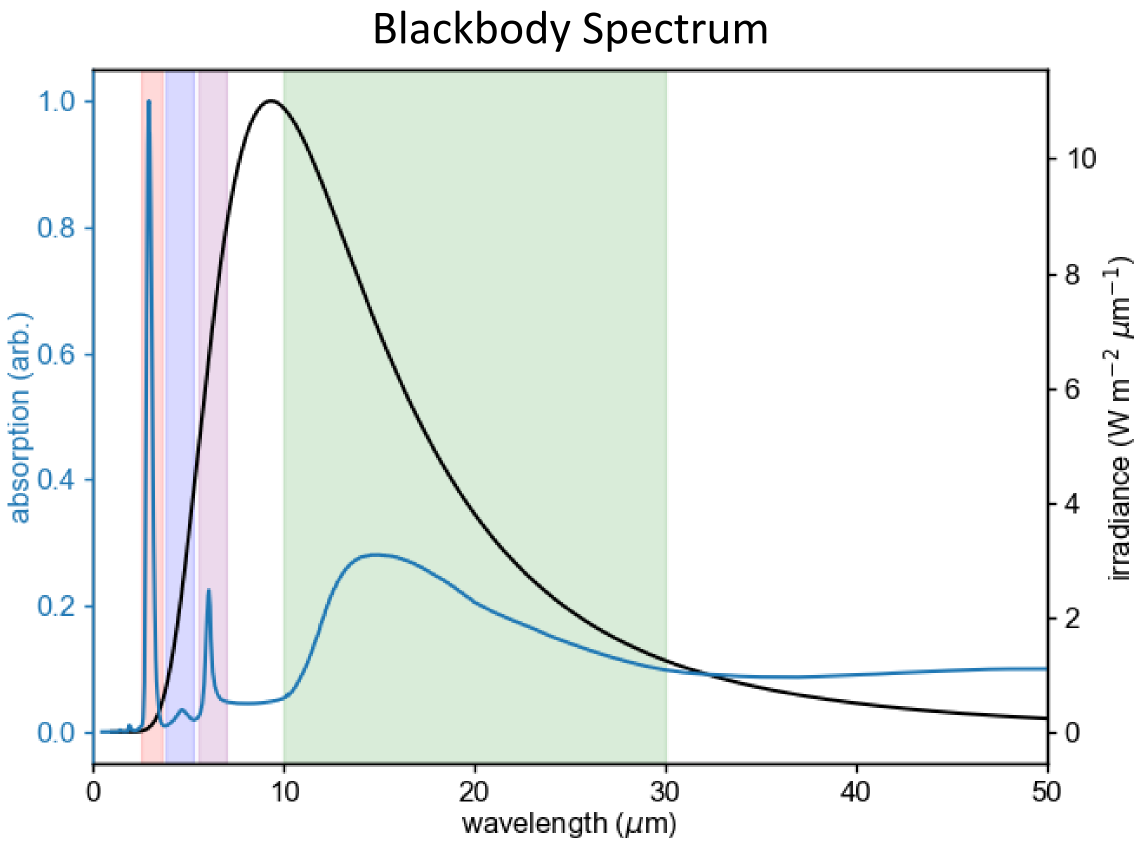
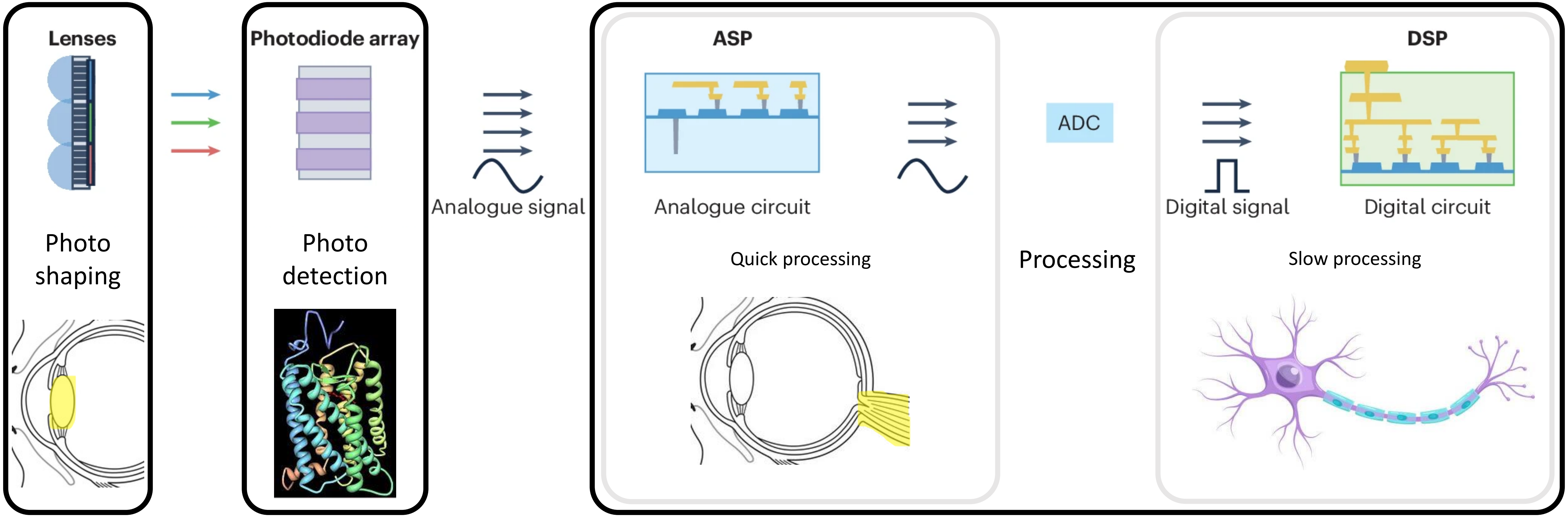
UC Riverside
University of California

(Nathan's) Water Bottle Conjecture



Can water be used for advanced infrared *vision sensing*?

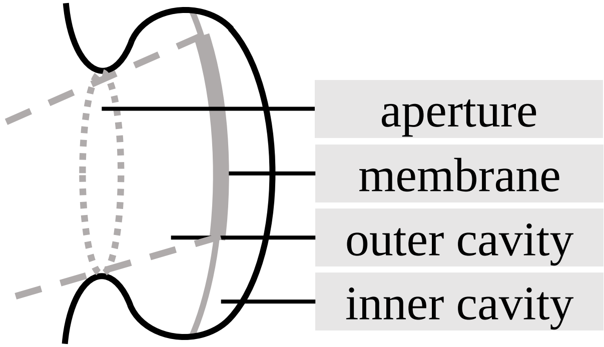
Layered Architecture in State-of-the-Art Vision Sensors

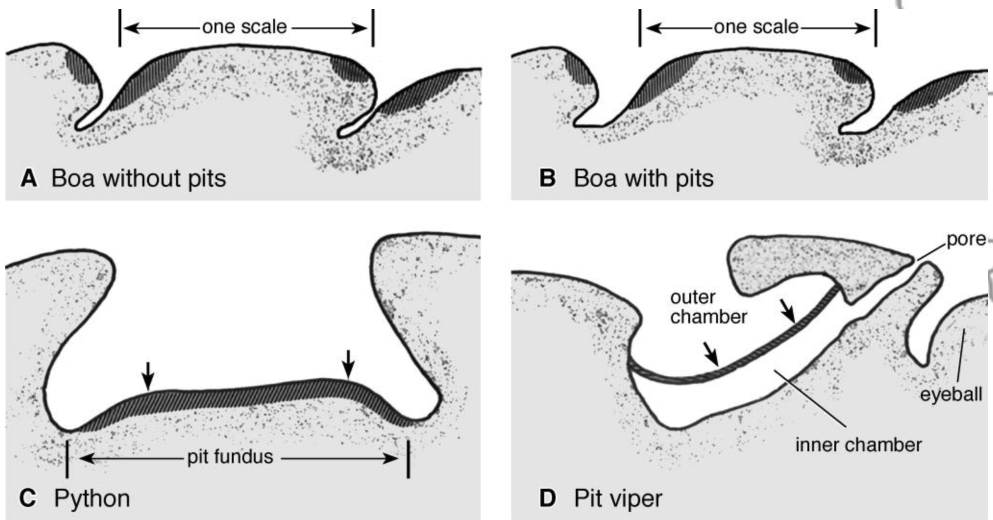


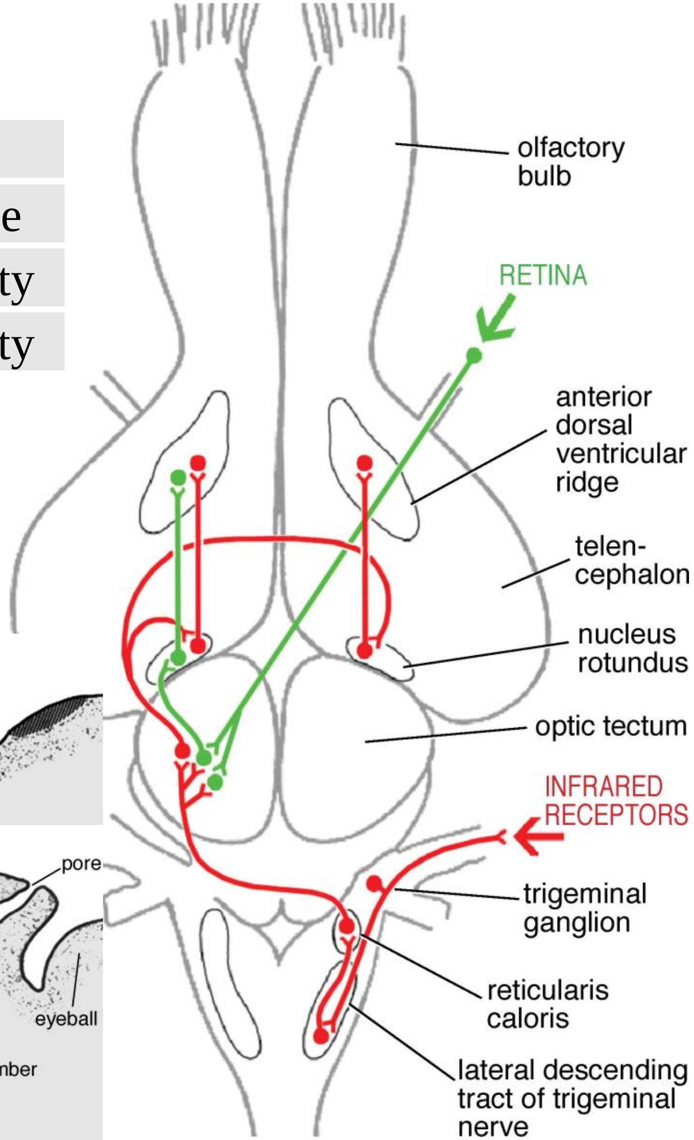
Biosystems exhibit remarkable (albeit not-fully-understood) solutions to the vision sensor challenge

Wang, Wan *Nat Nanotech* (2024)

Infrared Vision Sensing in the Pit Viper







IR vision *enhances* normal vision

multi-step interpretation

very fast $\sim 50 - 100$ ms

Goris *J or Herp* (2011)

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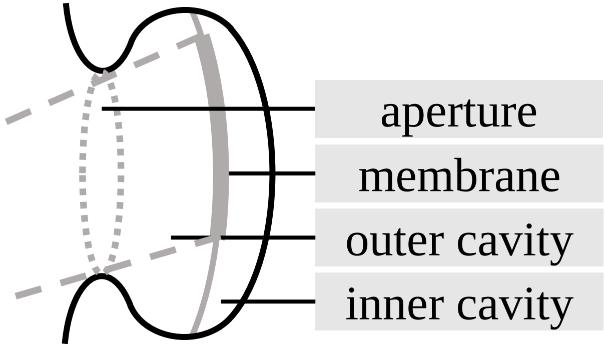
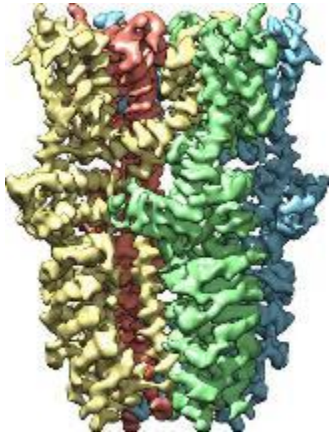
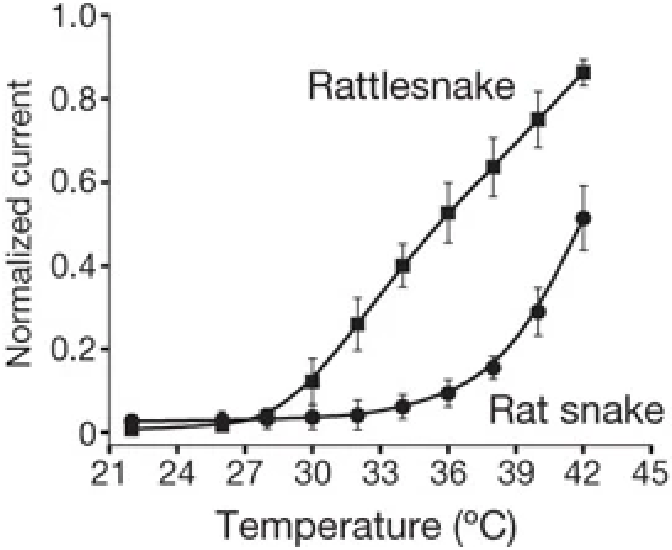




detection mediated by TRPA1 ion channels



- sensitive to temperature differences of < 0.002°C
- ion channels must be > 27°C

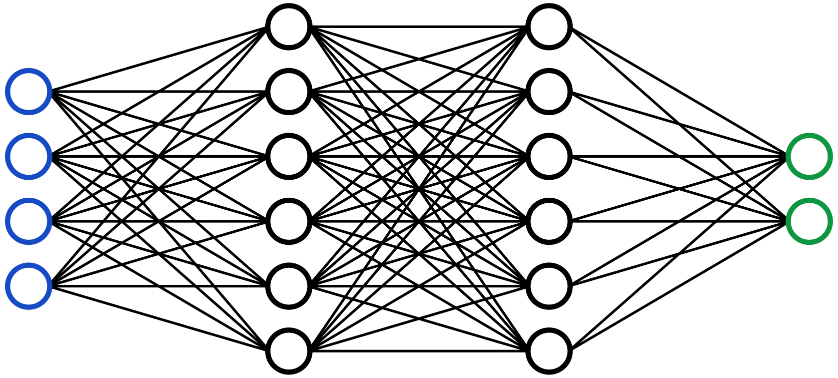
Hardware optimization problem:
light detection
vs.
image resolution

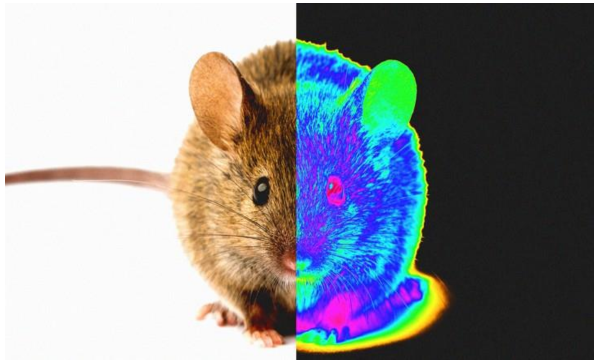
Gracheva et al. *Nature* (2010)

Proposal: Biologically Informed Infrared Vision

In humans, it takes ~250 ms to respond to visual stimulus,
~170 ms to respond to audio stimulus,
~150 ms to respond to a touch stimulus.

A pit viper can see, decide, and strike at a distance of one foot in 70 ms.

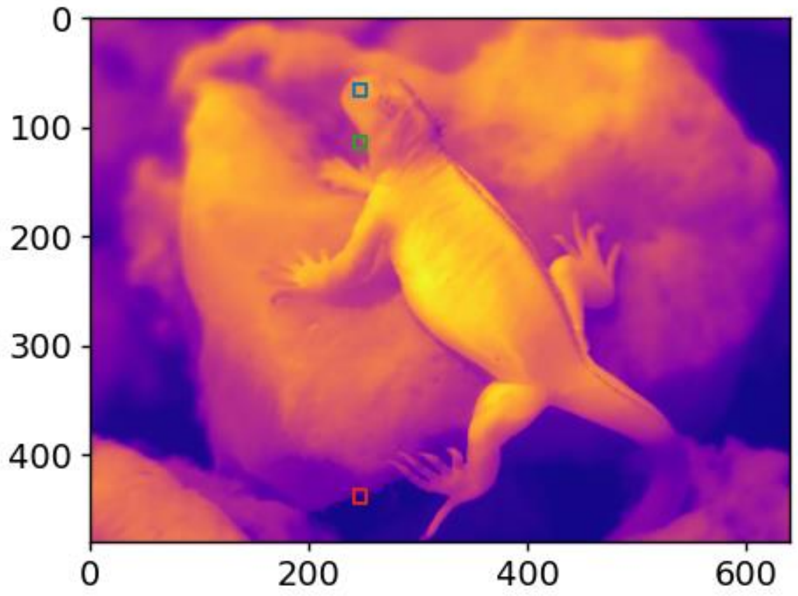




Given such seemingly low-resolution imaging hardware,
and such little computational power consumption,
how does the viper vision system work so efficiently?

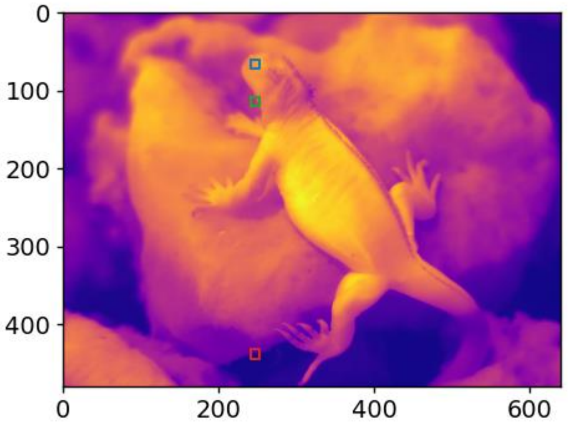
Water for Infrared Vision Sensing

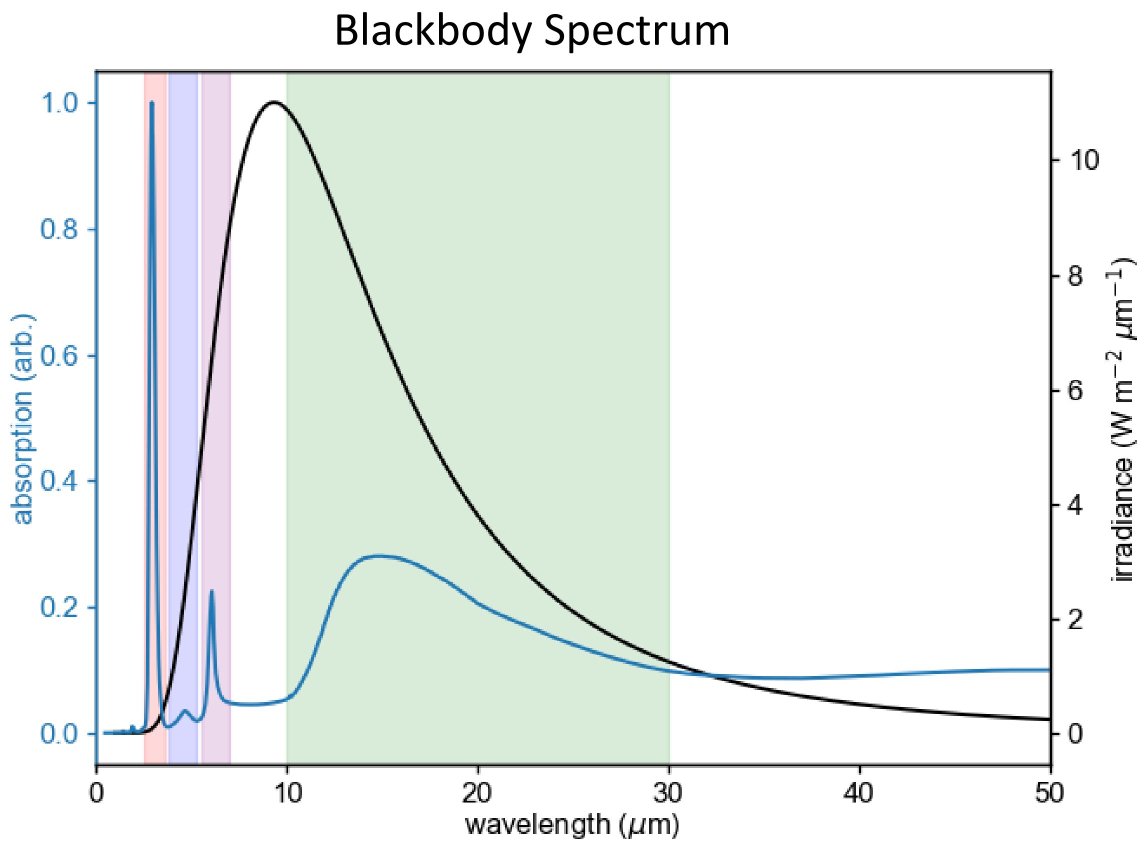
Temperature Image



How would a biological sensor best absorb infrared light?

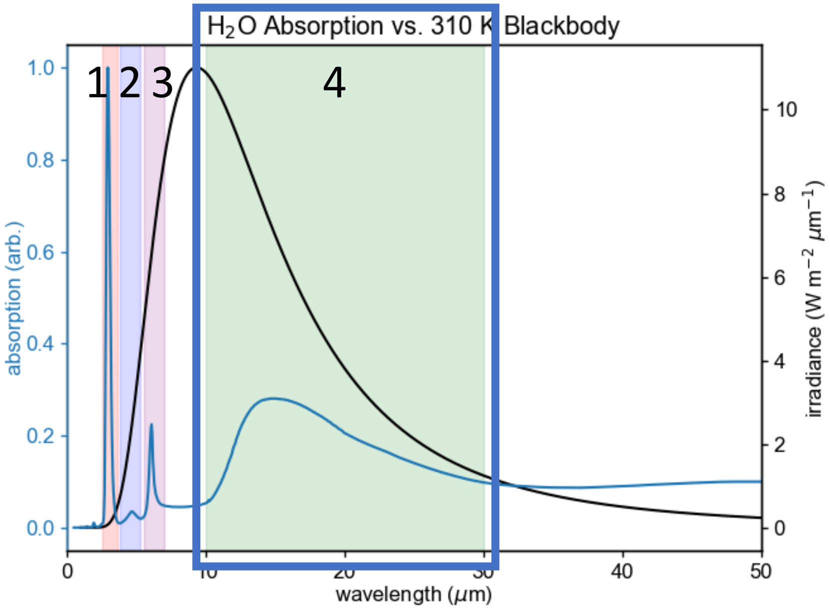
Water for Infrared Vision Sensing

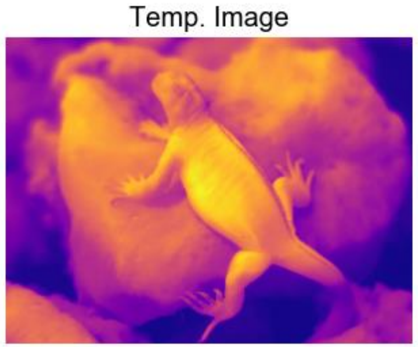


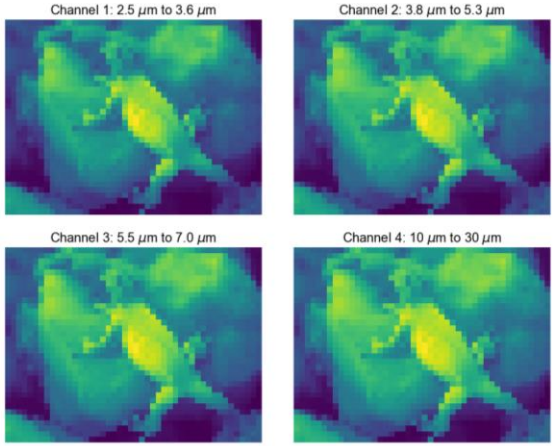


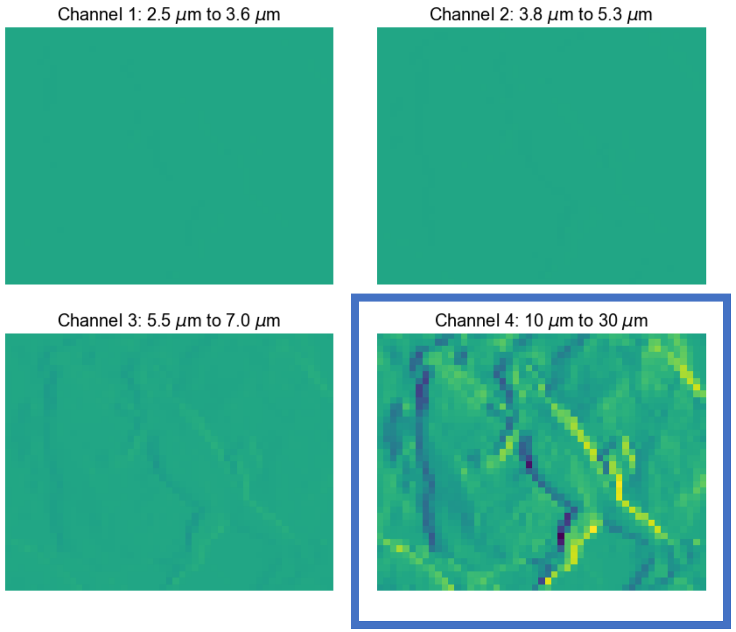
Water is an ideal IR absorber, except at the peak of the blackbody spectrum

Water for Infrared Vision Sensing









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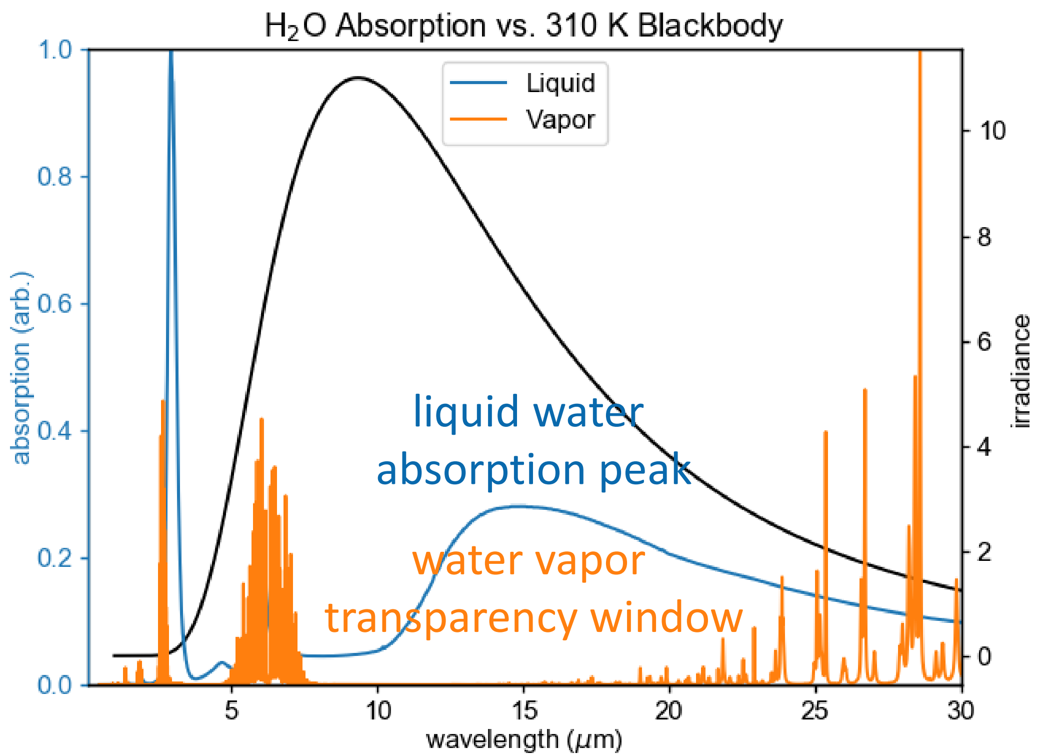

Is water the solution to the biological infrared vision problem?

Hypothesis: the viper IR vision system is utilizing the molecular rotation of water!

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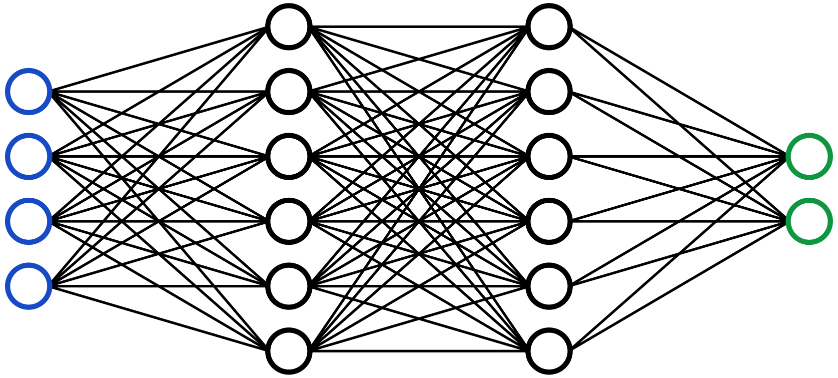

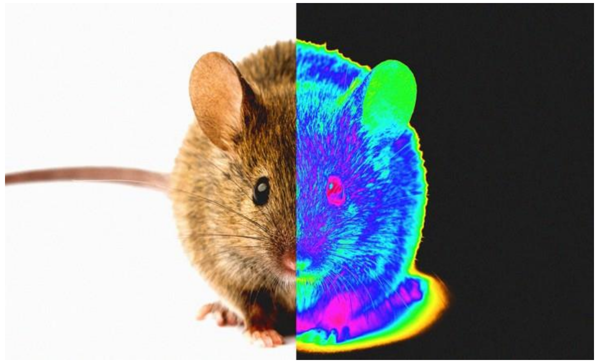

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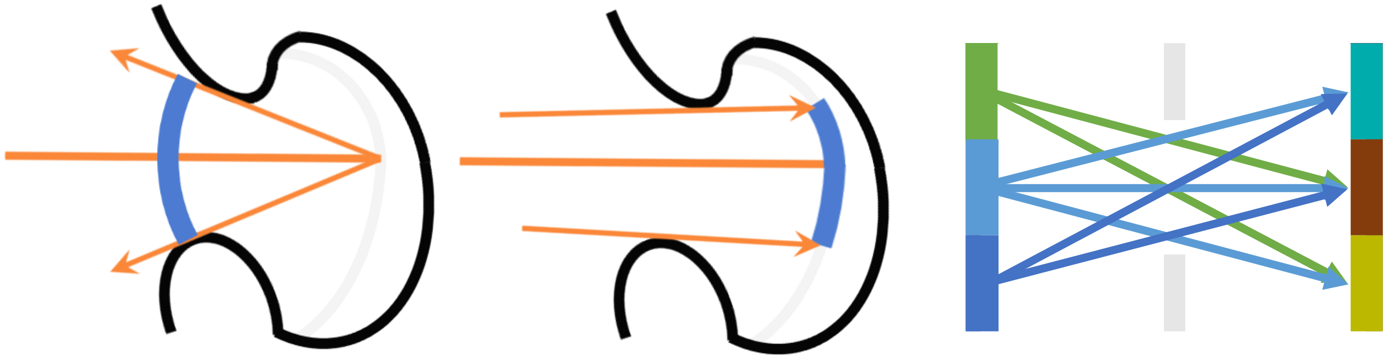
Lens-less Infrared Imaging

Optimization problem:

light detection vs image resolution



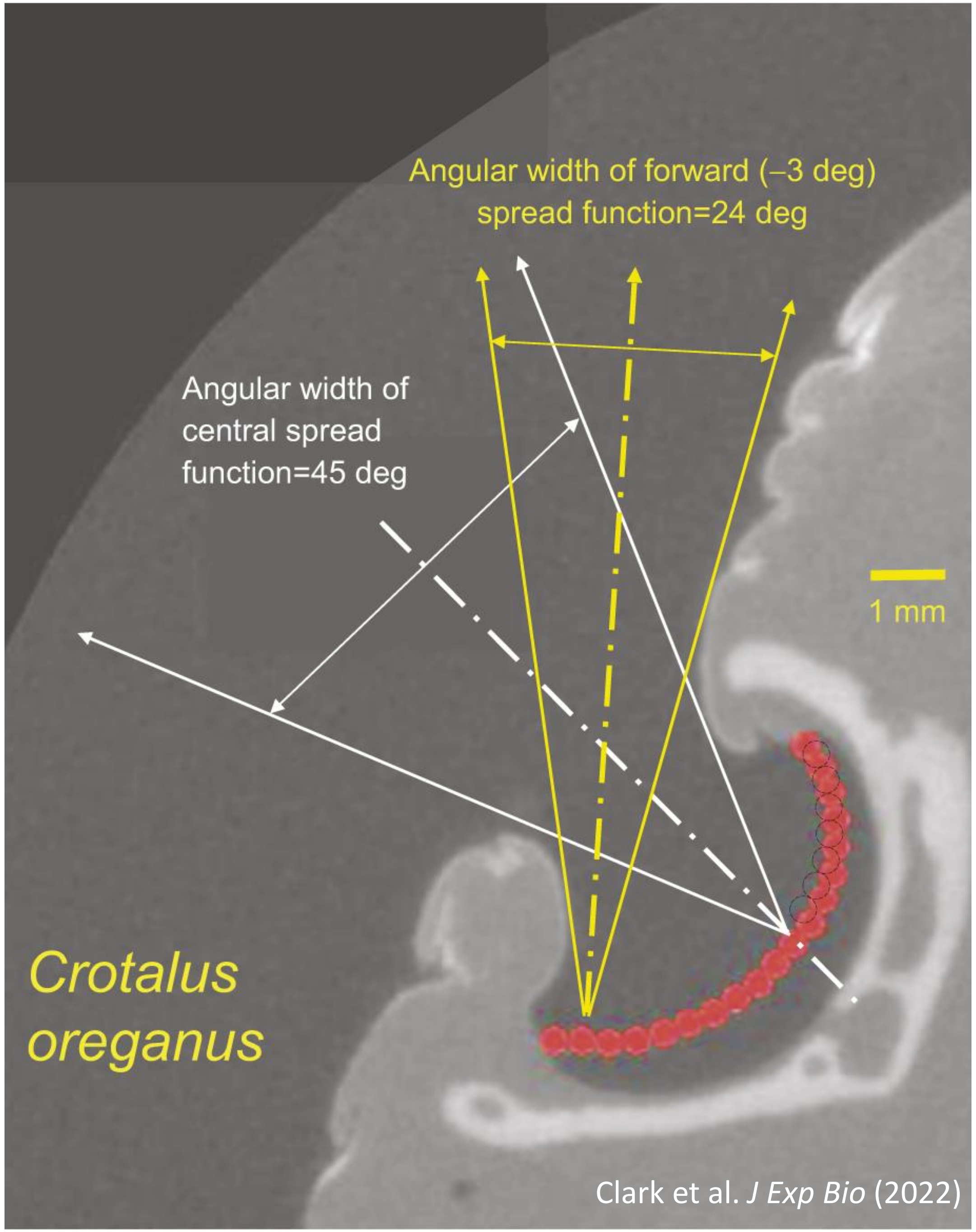
multiple emitters → single detector

single emitter → multiple detectors

- Transformation matrix $T_{\alpha}{}^{\beta}$
- Reconstruction:

$$[\text{image space}]_{\beta} = R_{\alpha}{}^{\beta}\,[\text{detector space}]_{\beta}$$

Sichert et al. *PRL* (2006)



Clark et al. *J Exp Bio* (2022)

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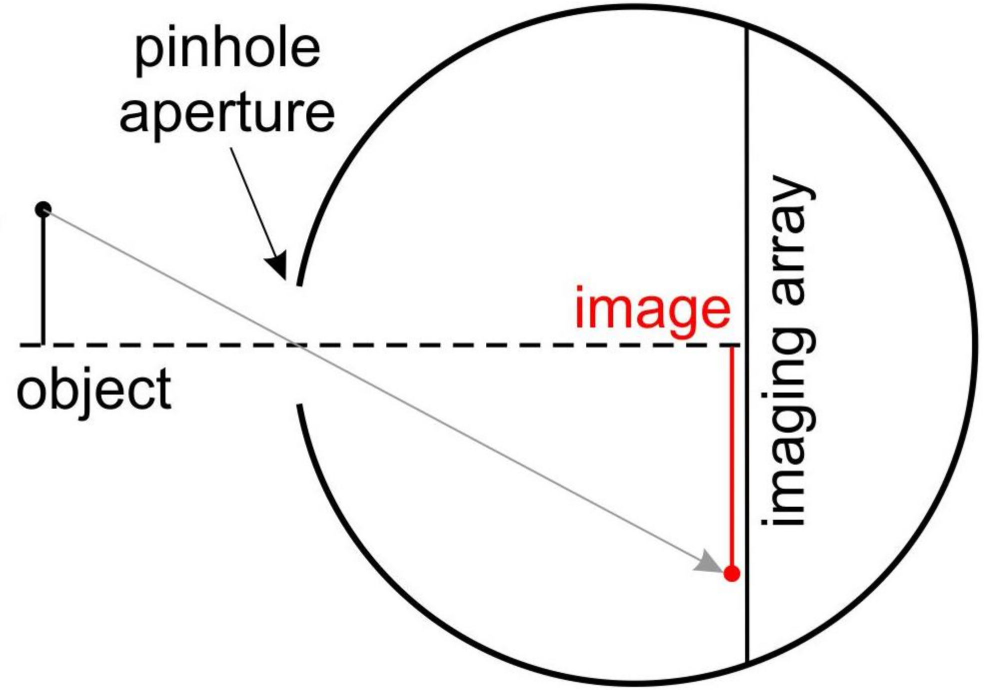
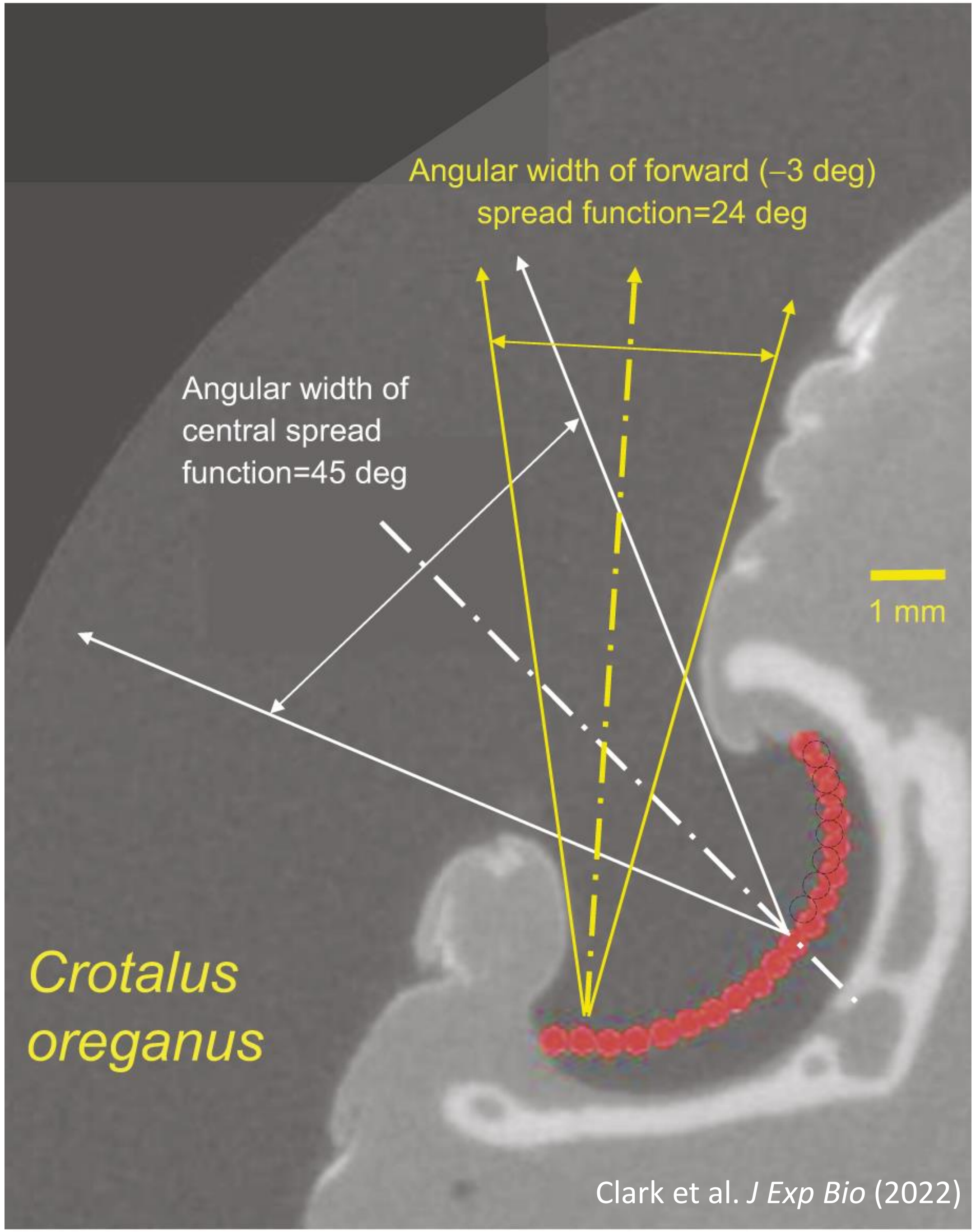
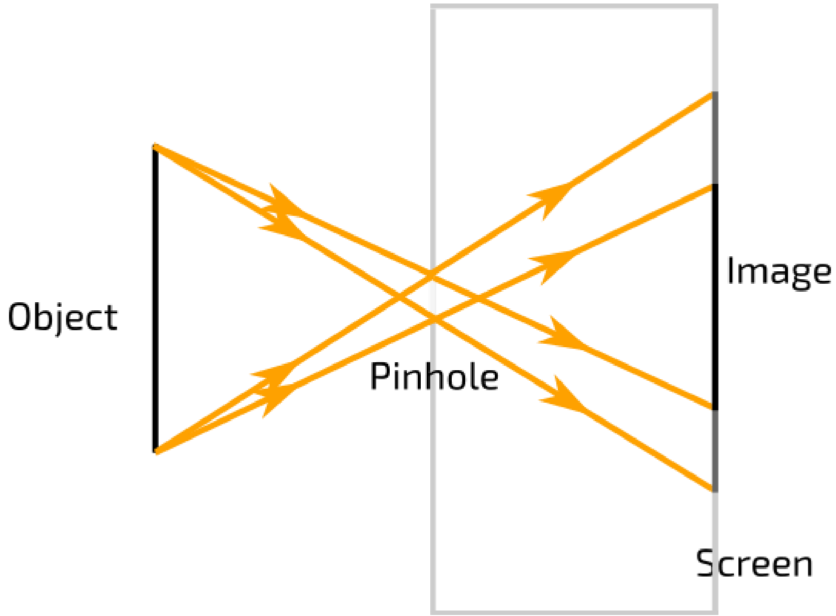




Lens-less Infrared Imaging: Pinhole Camera



$$T_\alpha{}^\beta = r_{\alpha\beta}^{-2} \cos \varphi_{\alpha\beta}$$

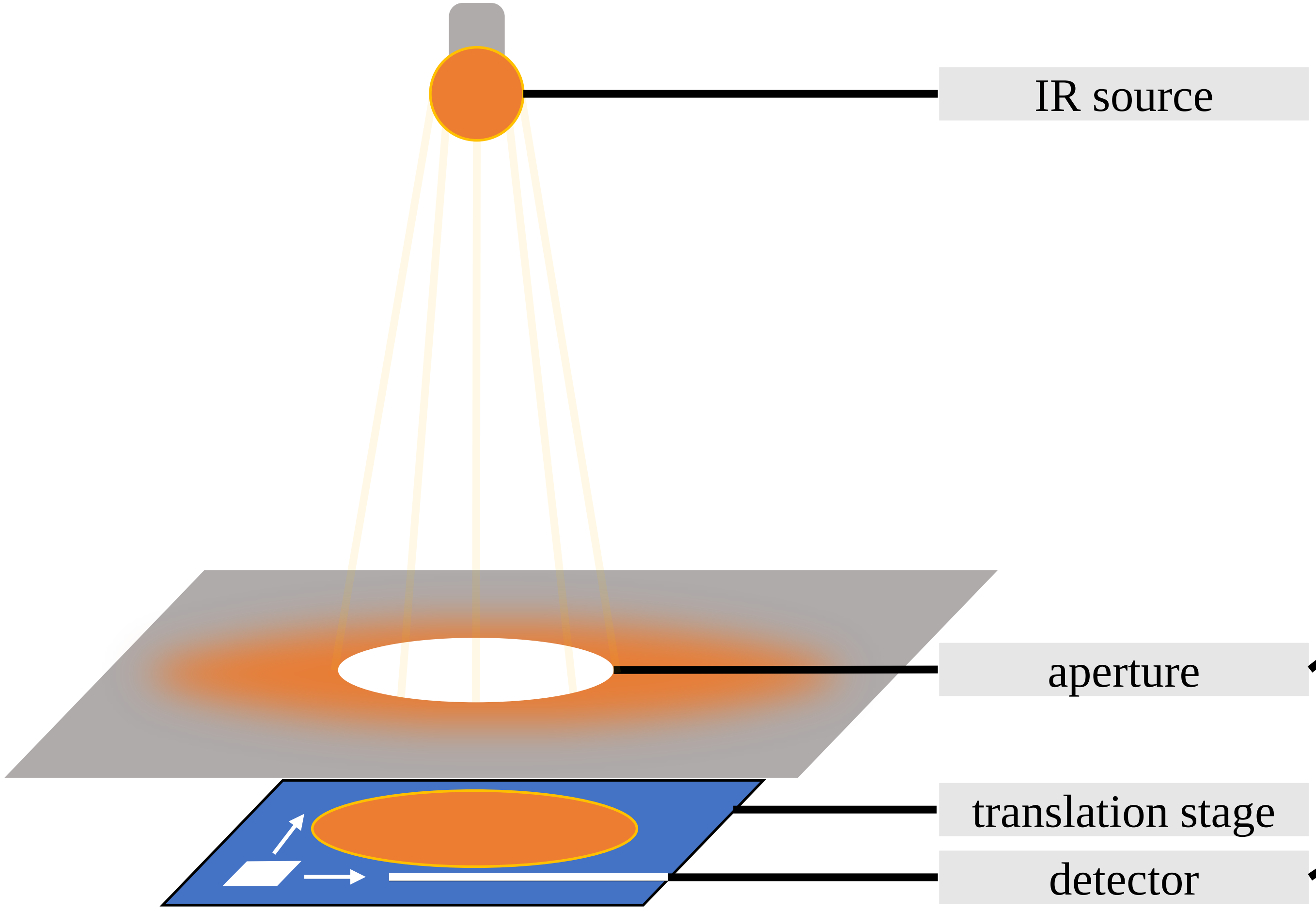
$$R^\mu{}_\gamma \left[T_\nu{}^\delta T^\gamma{}_\delta (1 + \tau^2) + \sigma^2 \delta_\nu^\gamma \right] = T_\nu{}^\mu$$

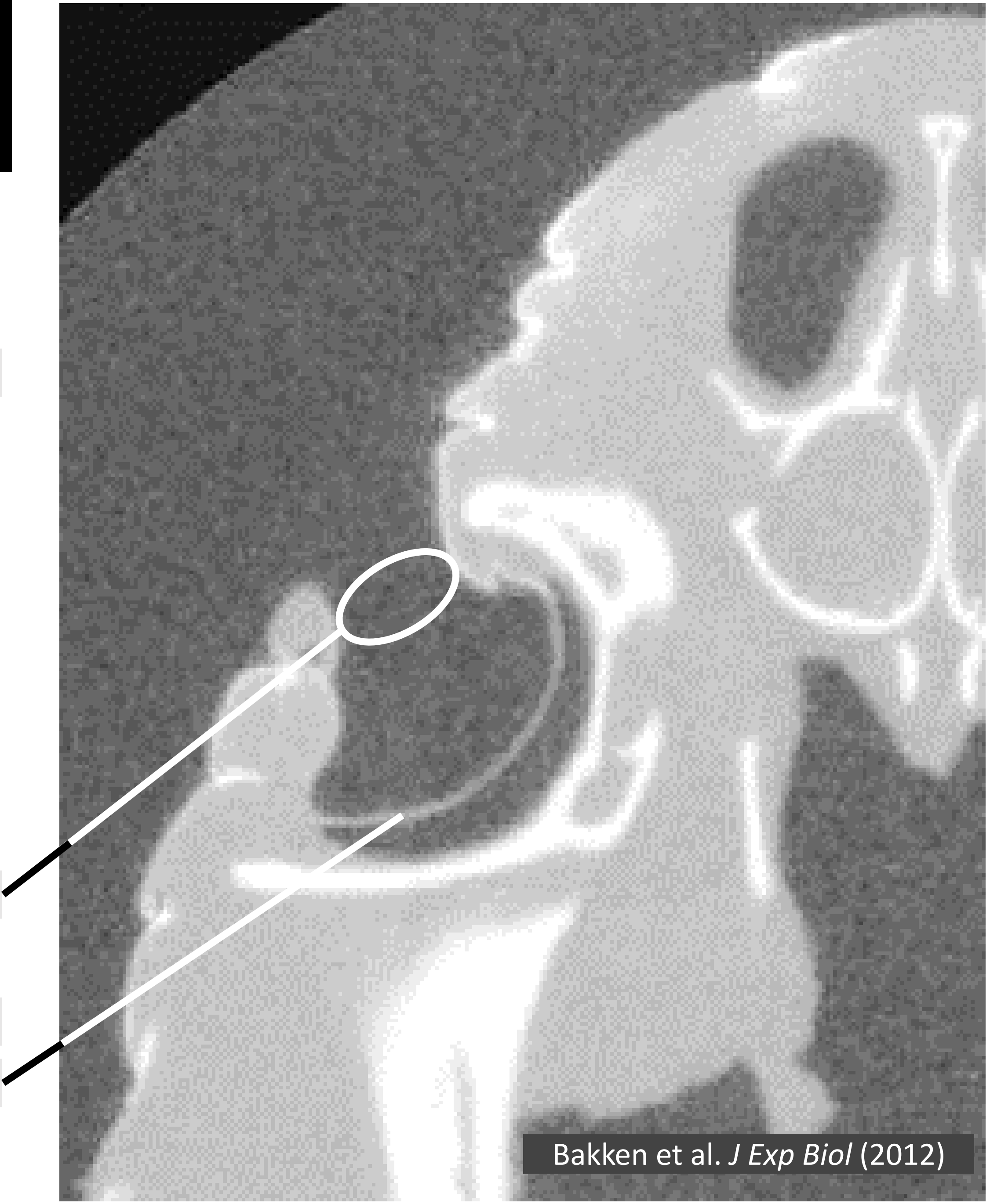
$$I_\alpha = R_\alpha^\beta S_\beta$$

At each point in space, we first calculate the heat distribution on the membrane for a given heat distribution in space.

In only one computational step, we then use stochastic reconstruction to estimate the input image from the measured response on the membrane.

Lens-less Infrared Imaging





Bakken et al. *J Exp Biol* (2012)

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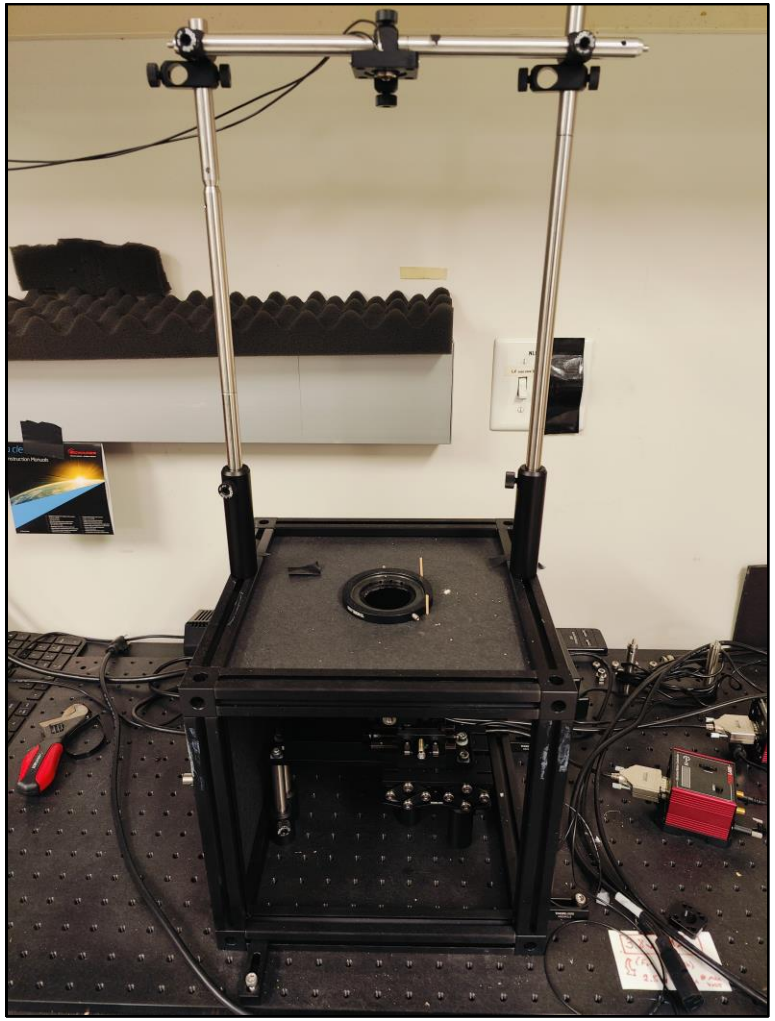

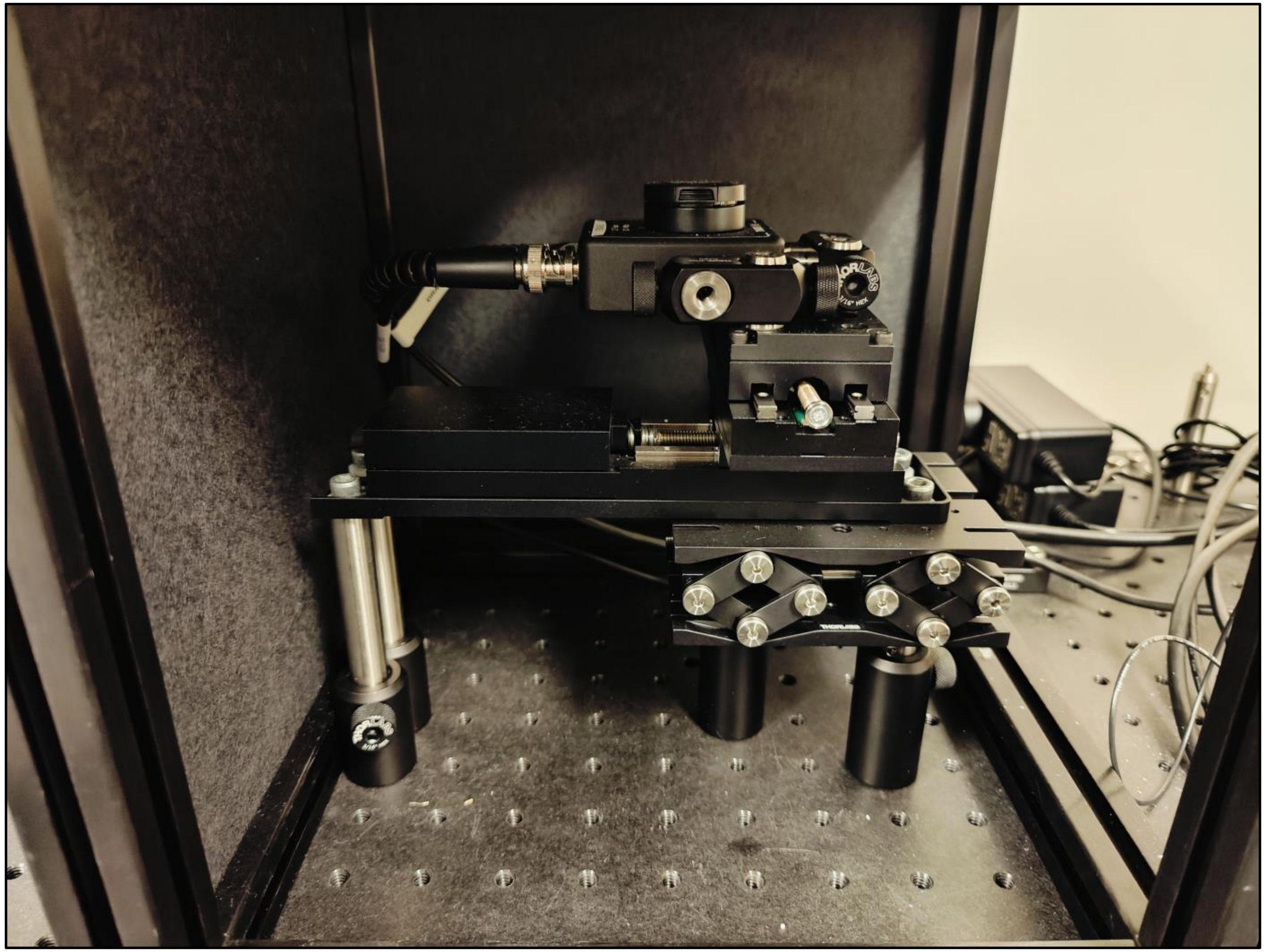

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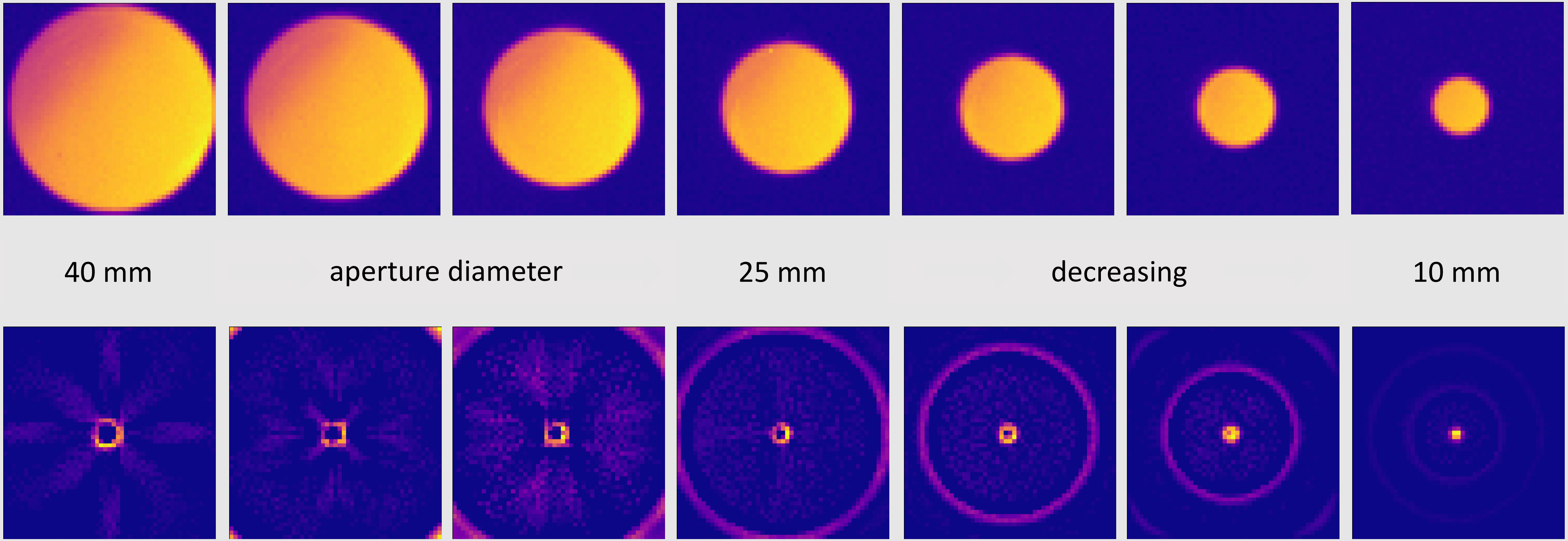
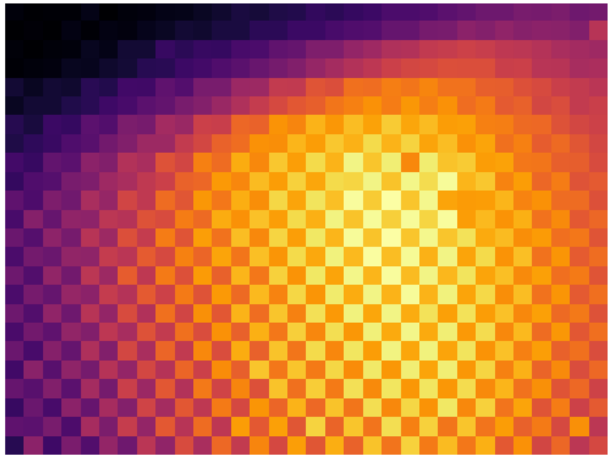
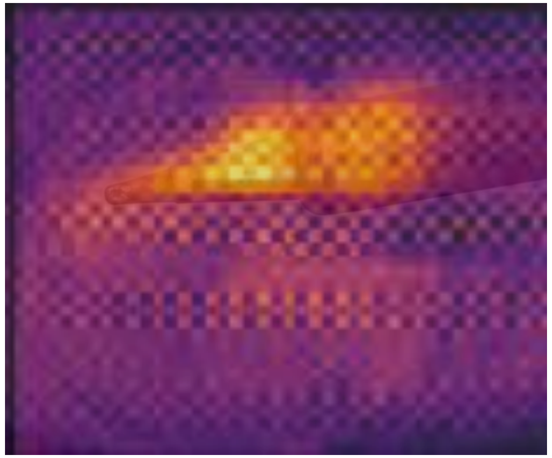
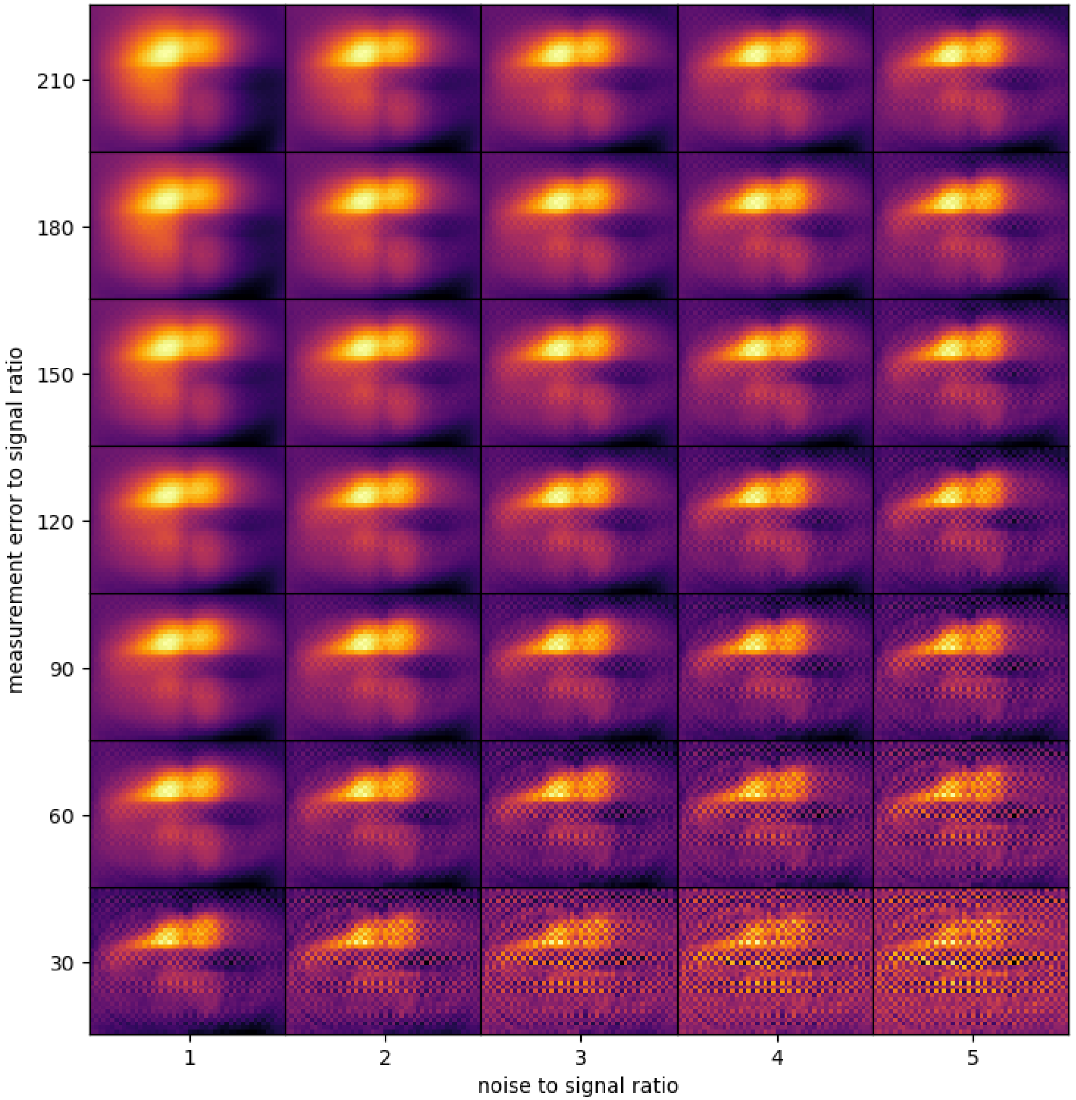


A closed aperture (10 mm) reproduces the point source and rejects stray light,
as expected from a pinhole camera

Lens-less Infrared Imaging: Commercial Sensor







With a **lens-less** commercial IR photocell array, our protocol outperforms the imaging quality of the packaged device

With advanced sensors, can we do even better?

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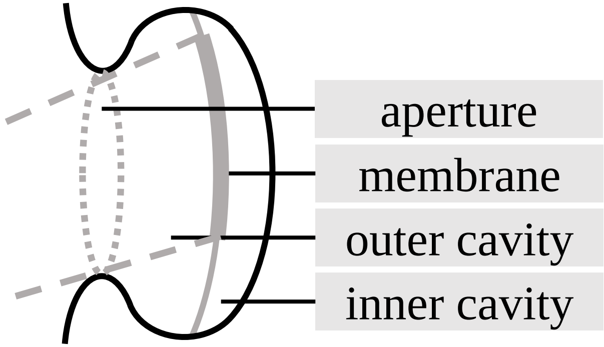

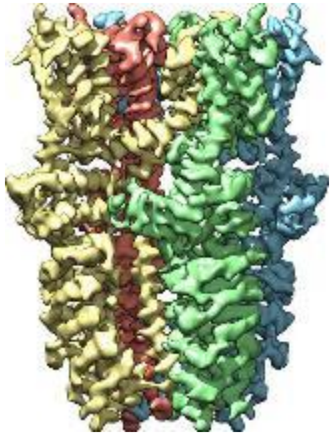

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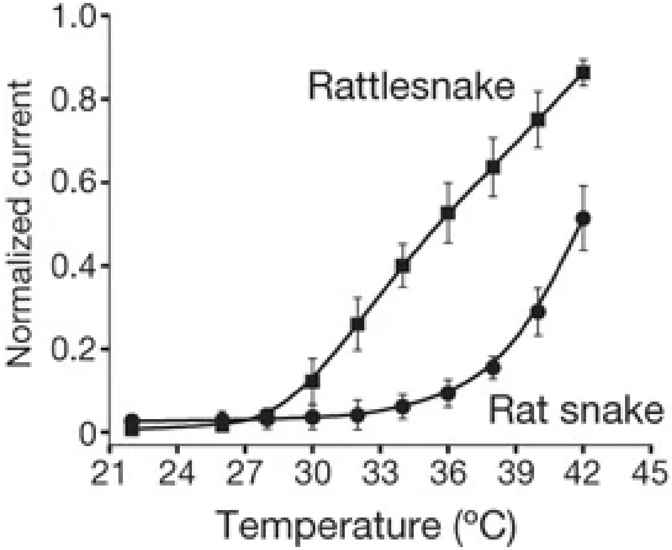

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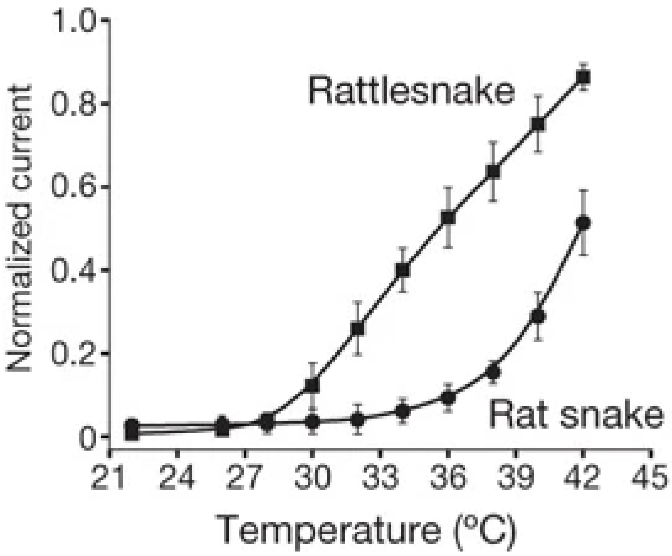
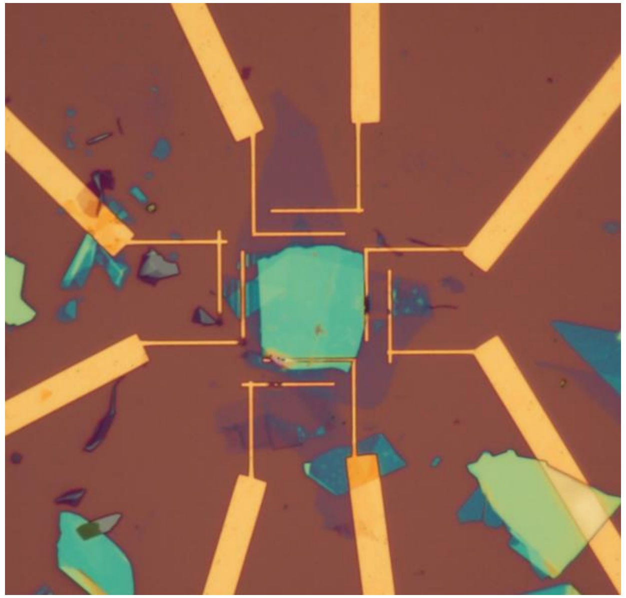
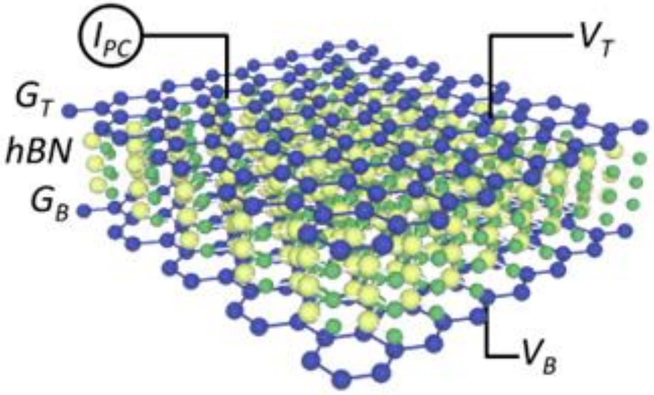
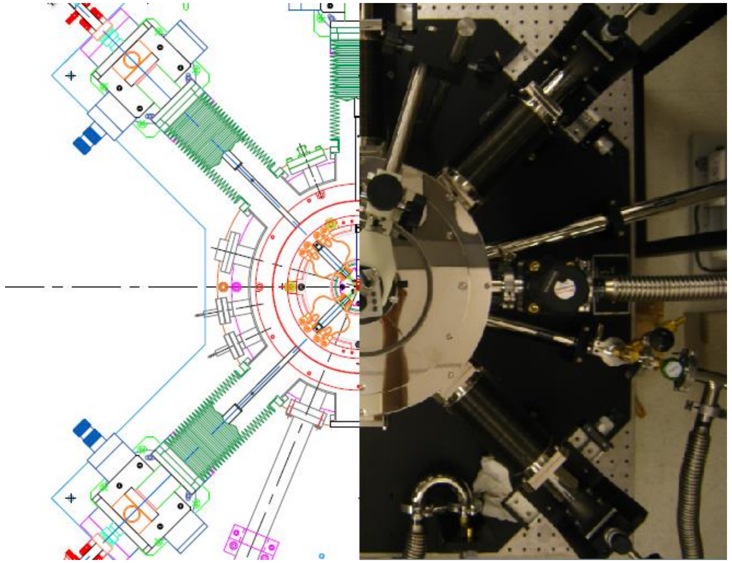


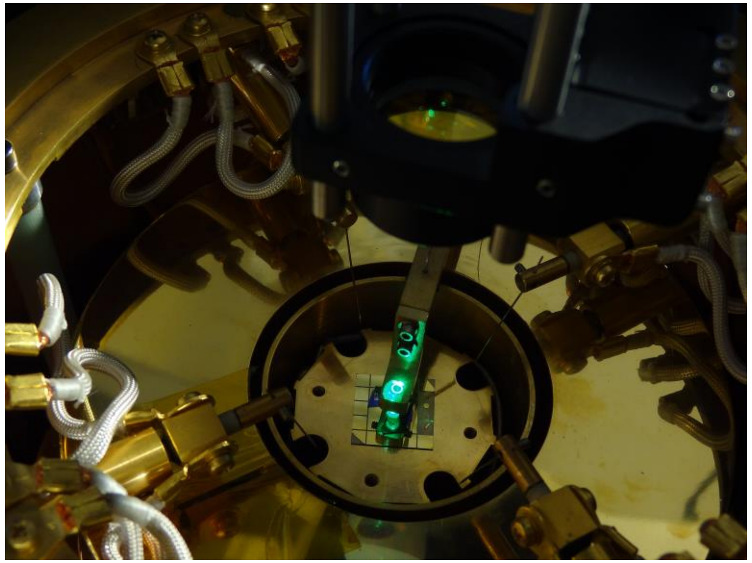
The pit viper utilizes a fast, nanoscale temperature sensor with sharp super-linear threshold behavior

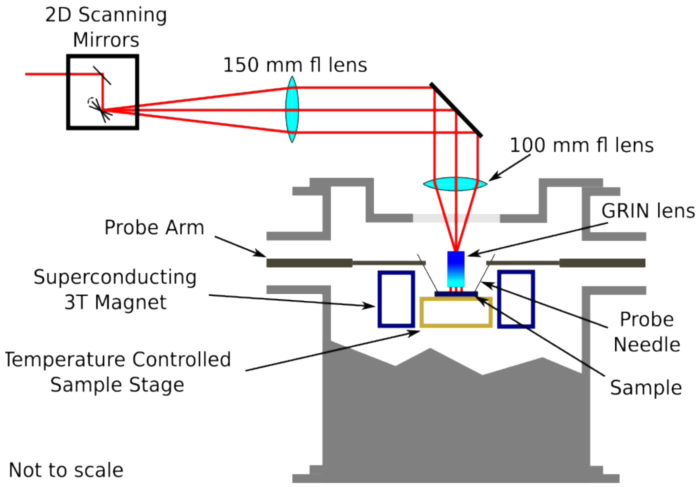
Infrared Nanoscale Optoelectronics in the Gabor Labs

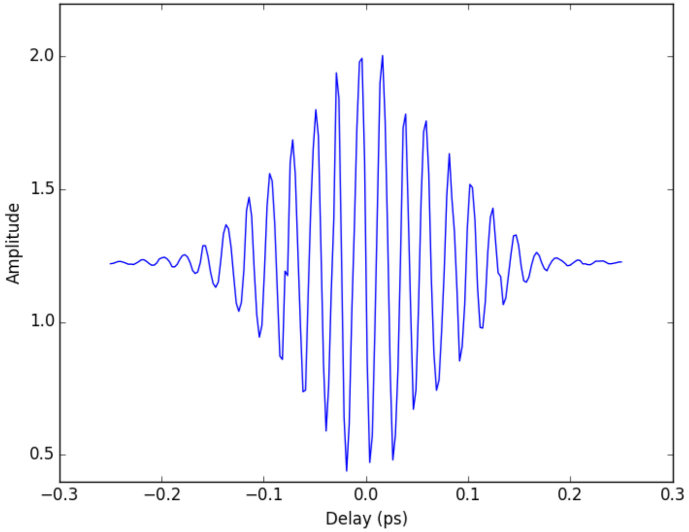




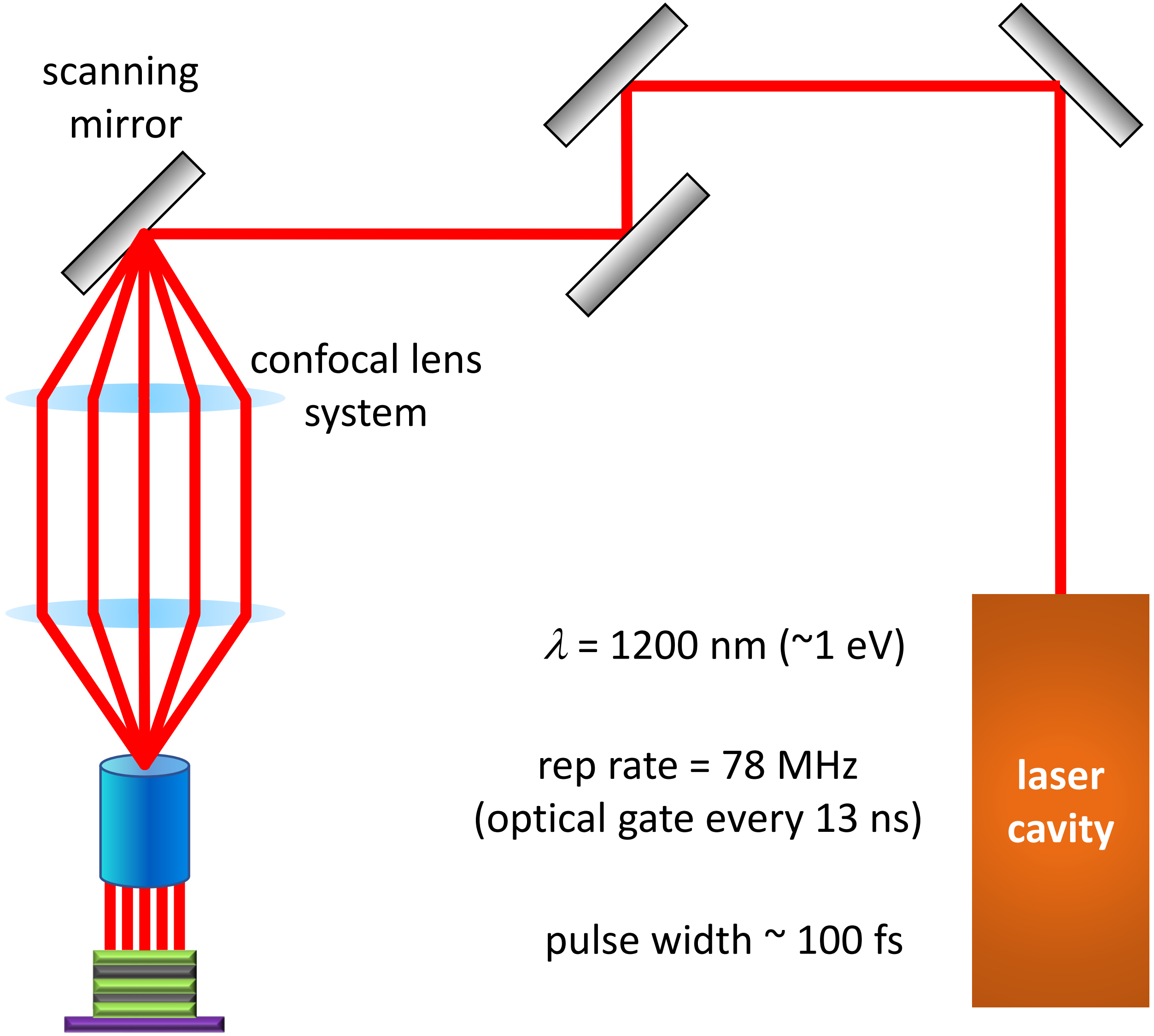


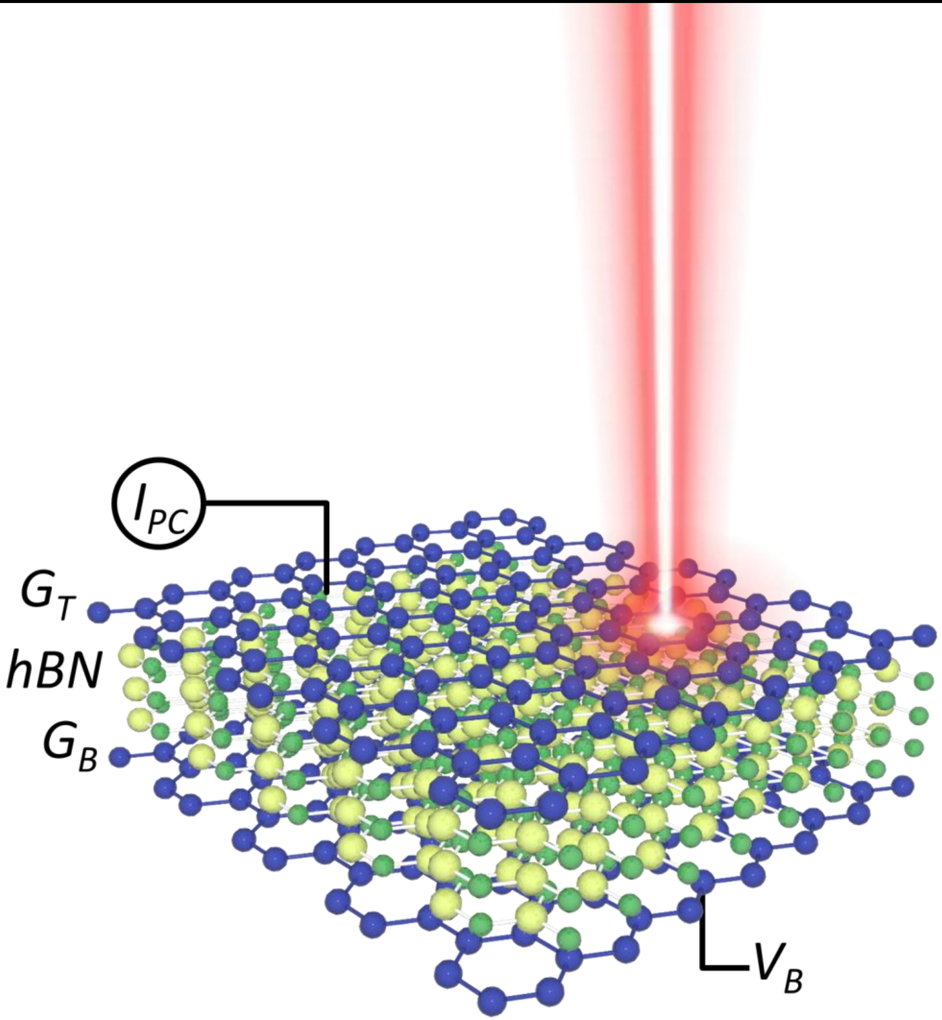






Infrared Nanoscale Optoelectronics Based on Graphene





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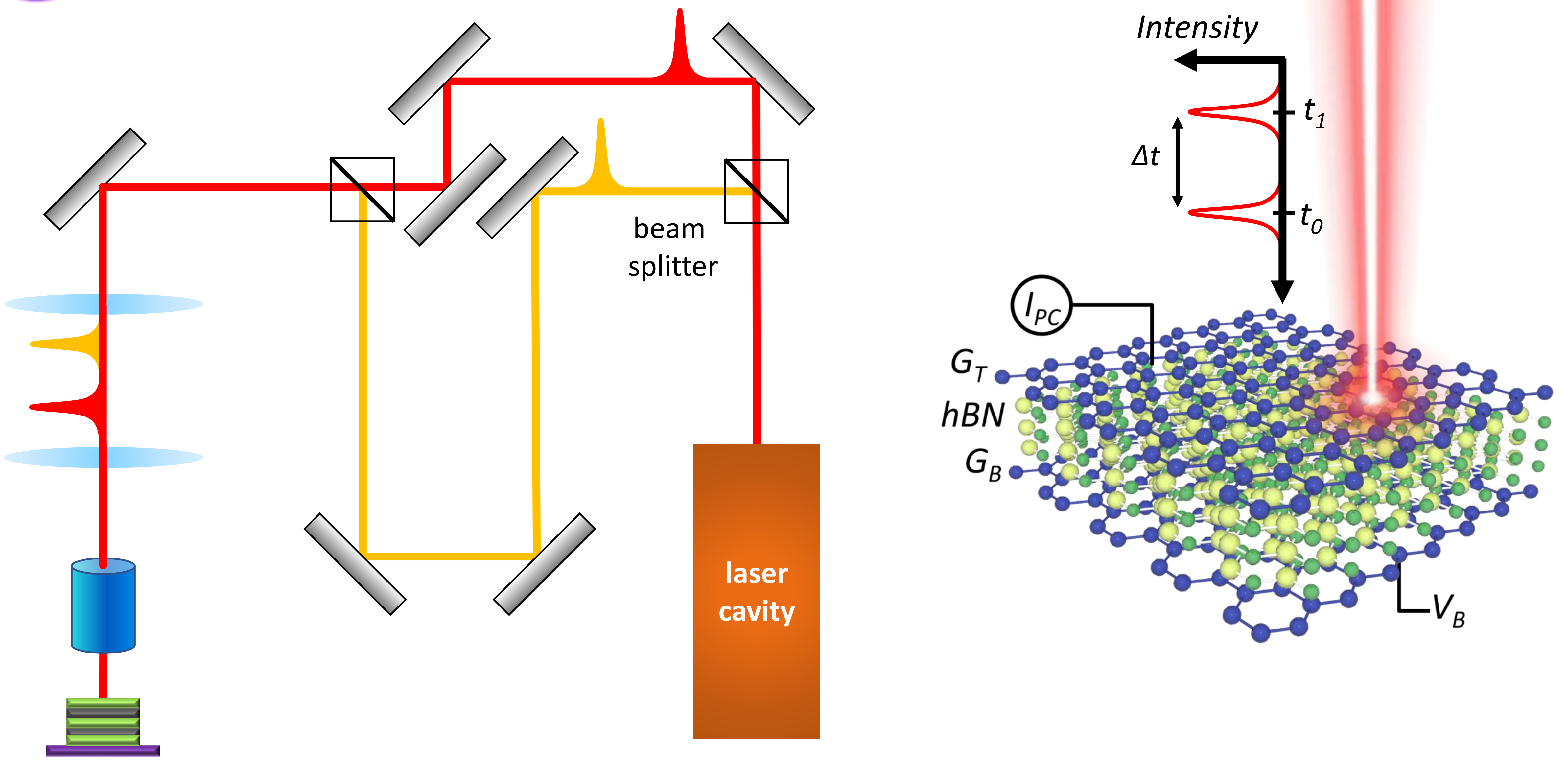

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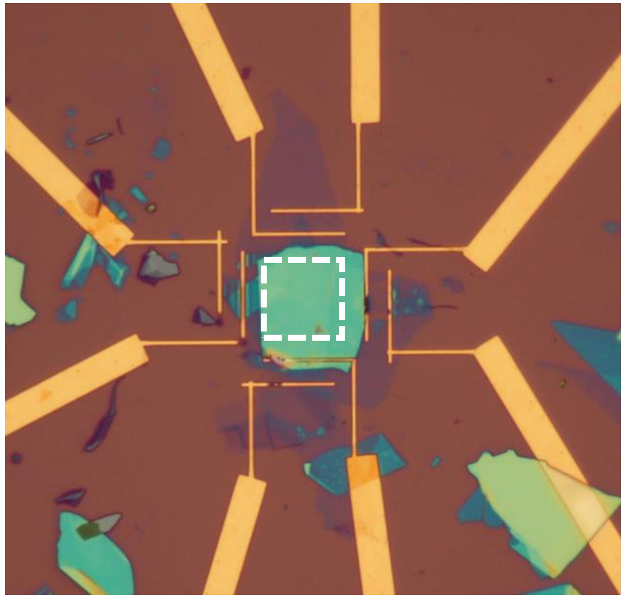

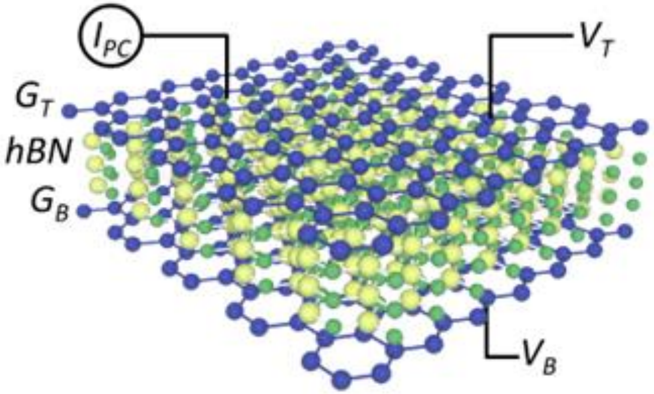

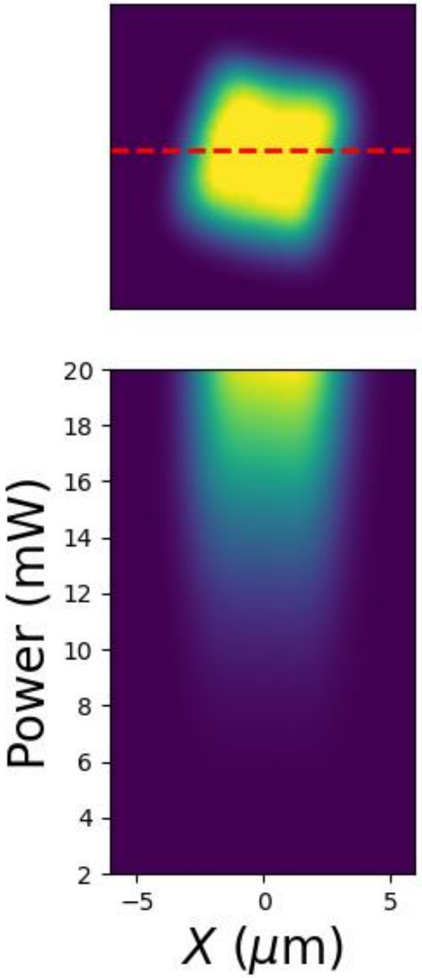

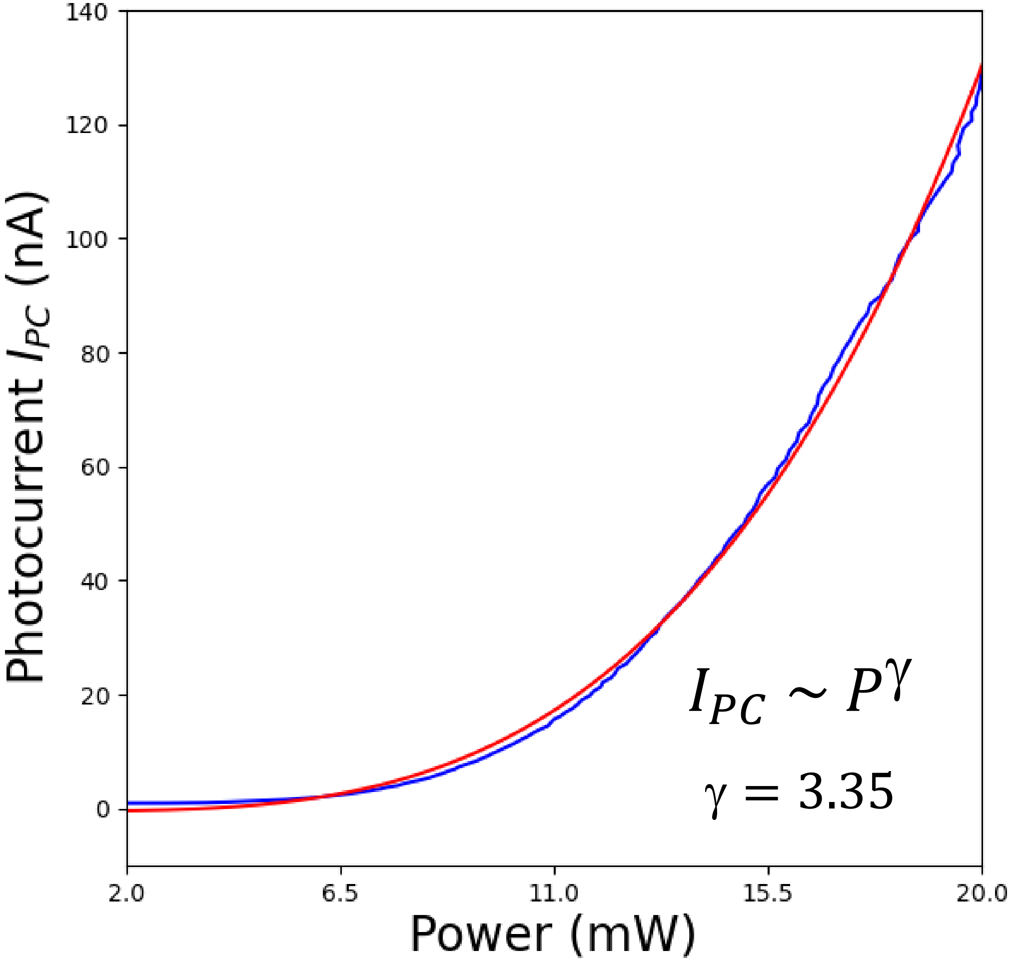

sharp super-linear threshold behavior

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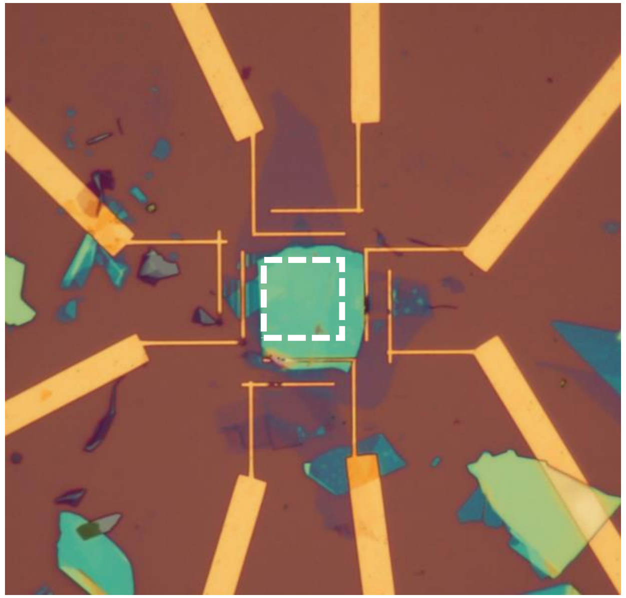

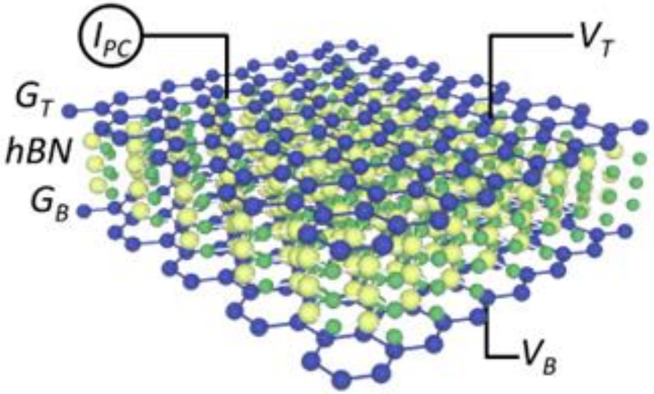

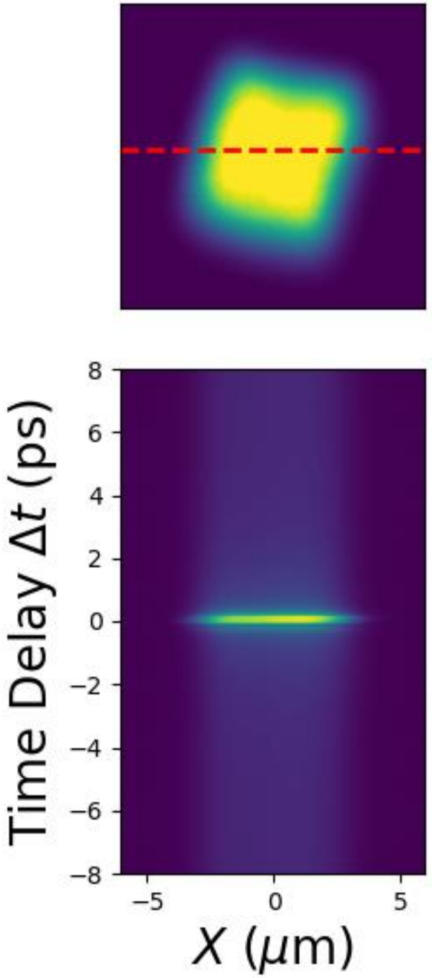

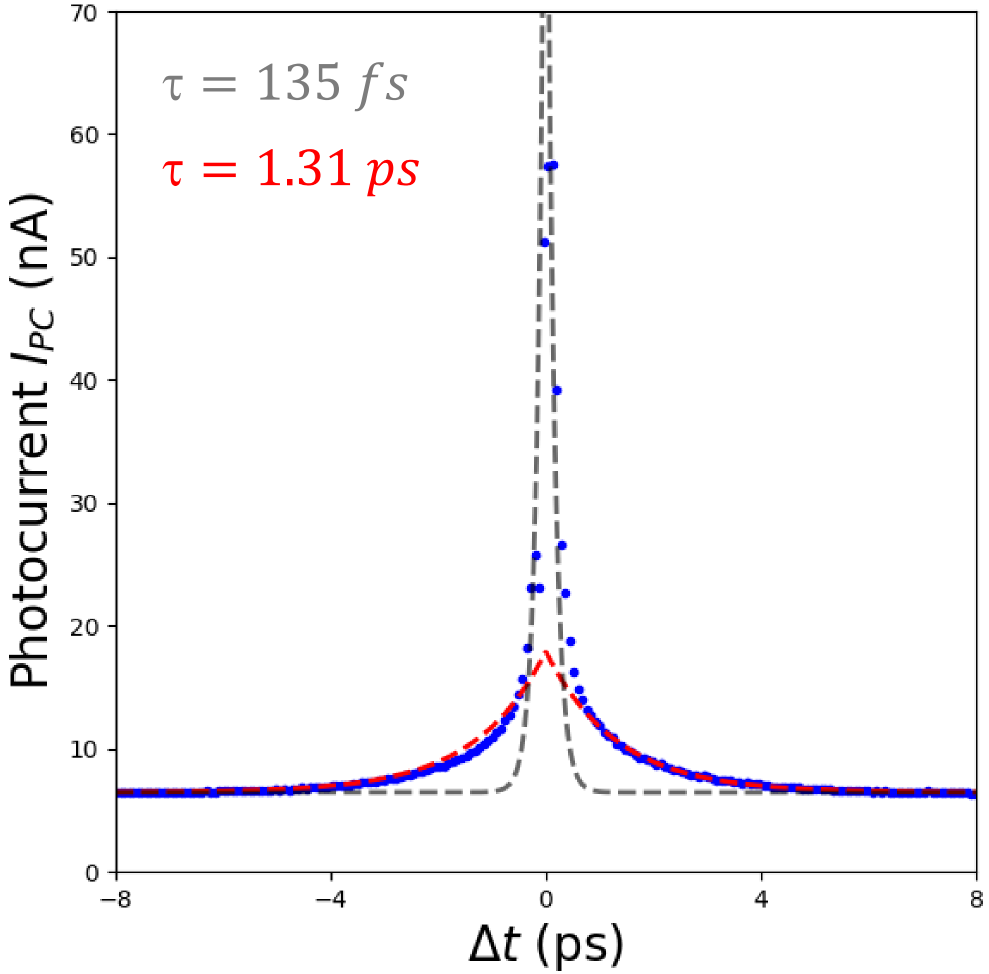

(ultra)fast, nanoscale temperature sensor

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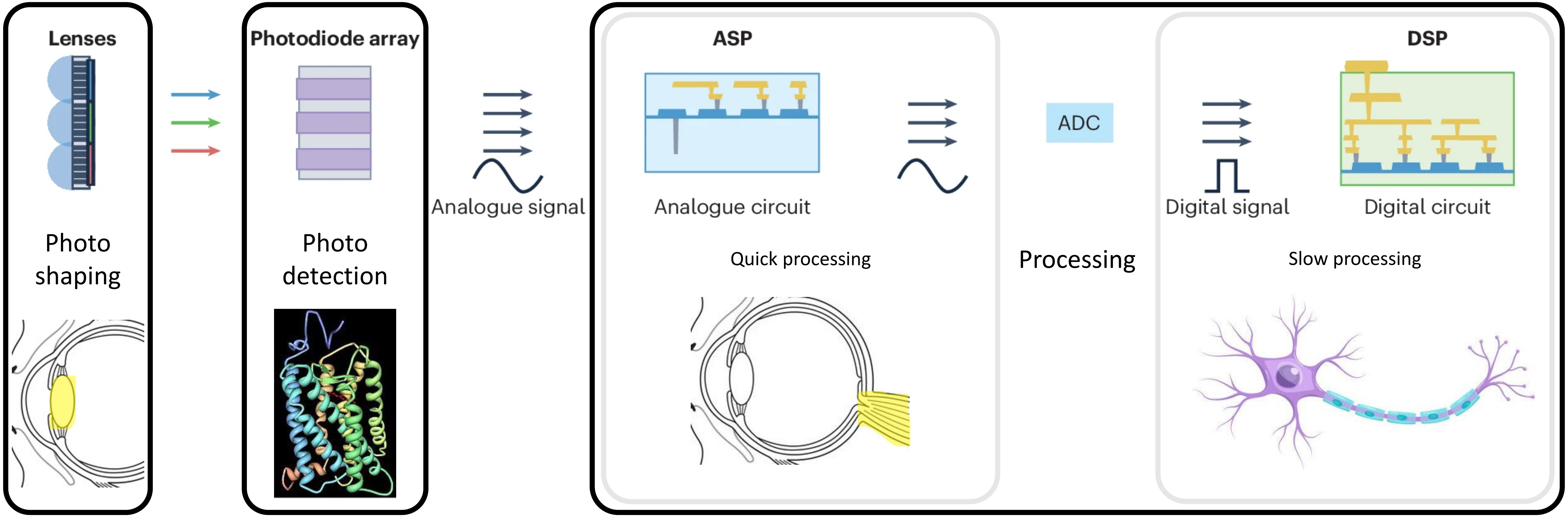

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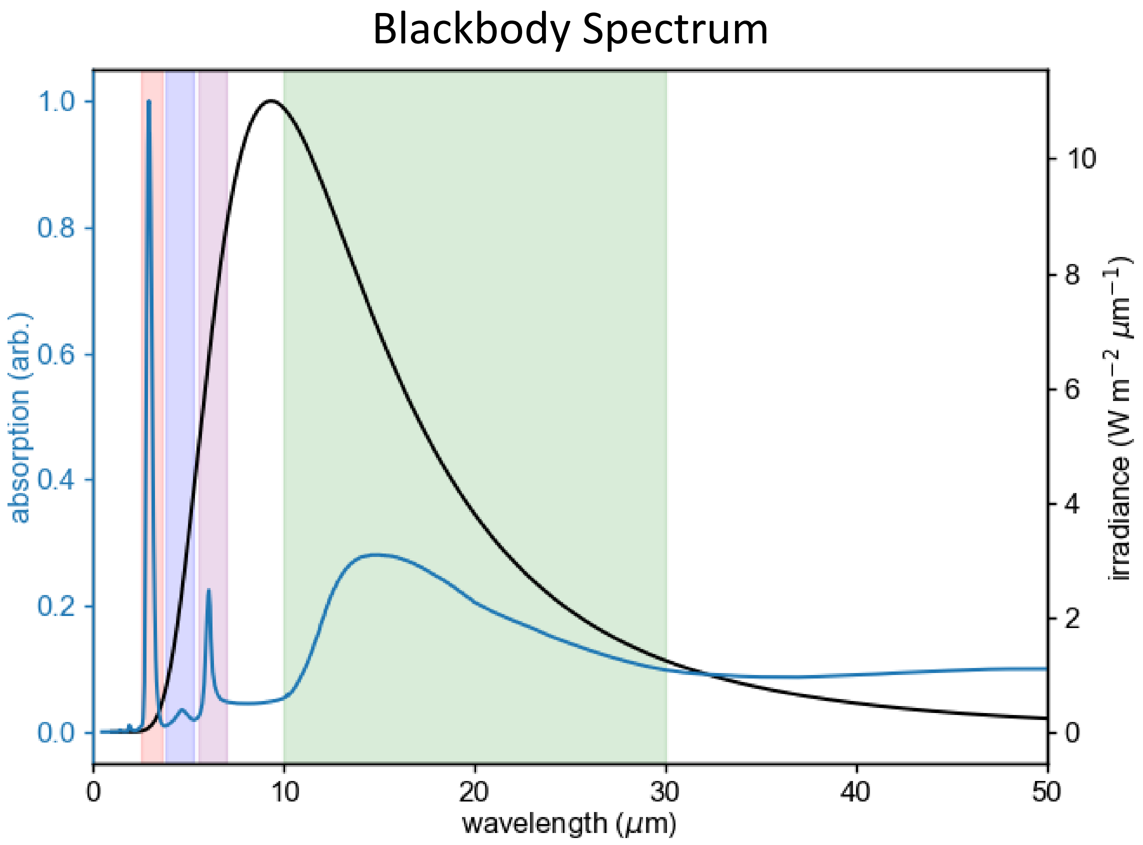
Wang, Wan *Nat Nanotech* (2024)

(Nathan's) Water Bottle Conjecture



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Acknowledgements

QMO Lab

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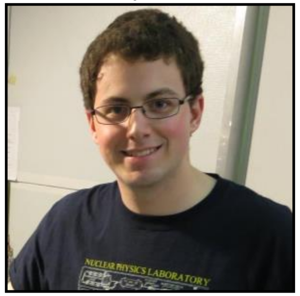
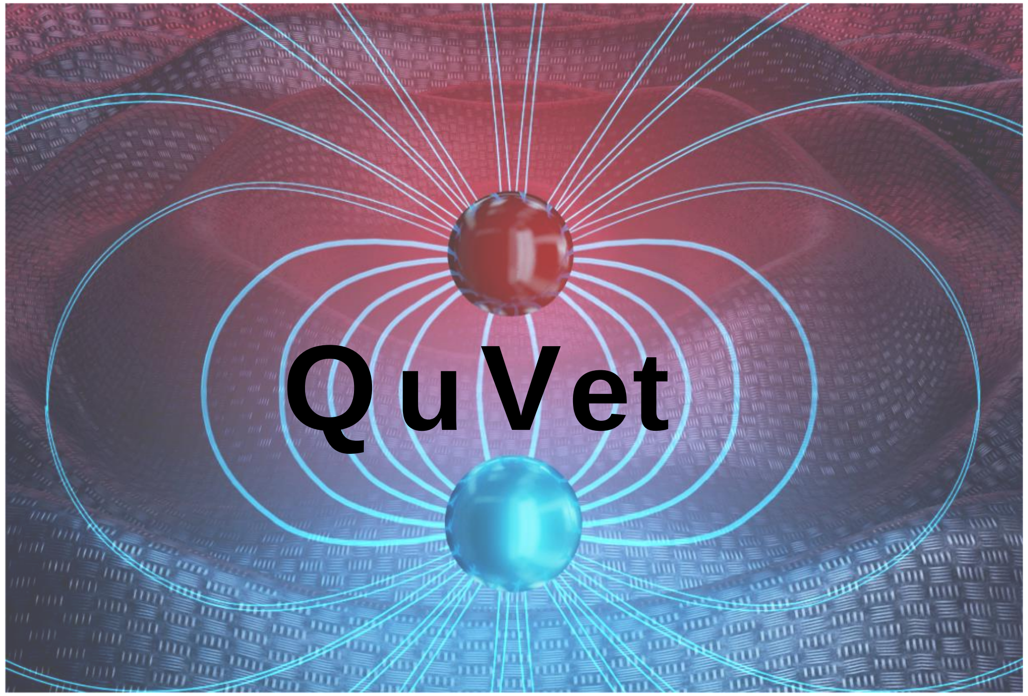
Vivek Aji

Zachary Miller



Trevor Arp



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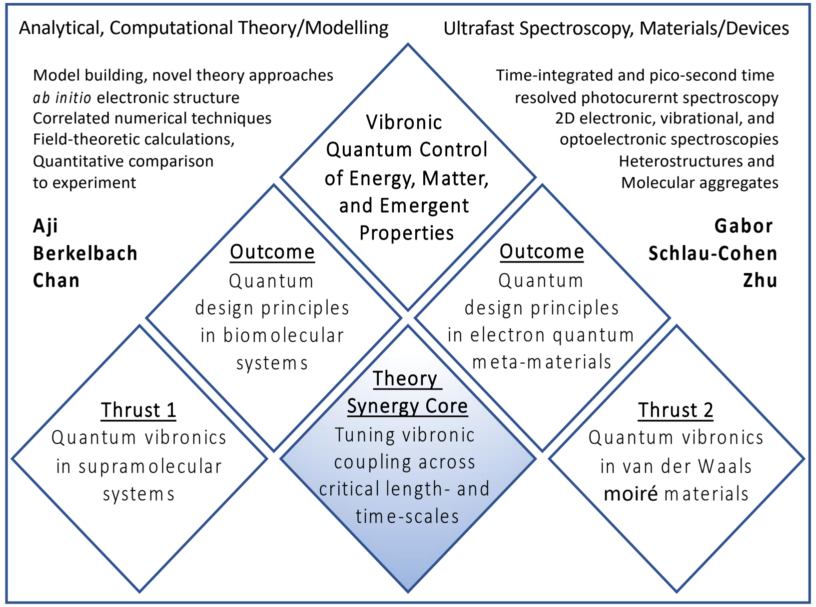
PI: Nathaniel Gabor (UCR)



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Gabriela Schlau-Cohen (MIT)

Vivek Aji (UCR)

Tim Berkelbach (Columbia)

Garnet Chan (Caltech)