Advances in Far-Infrared Detector Technology

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Caltech/JPL

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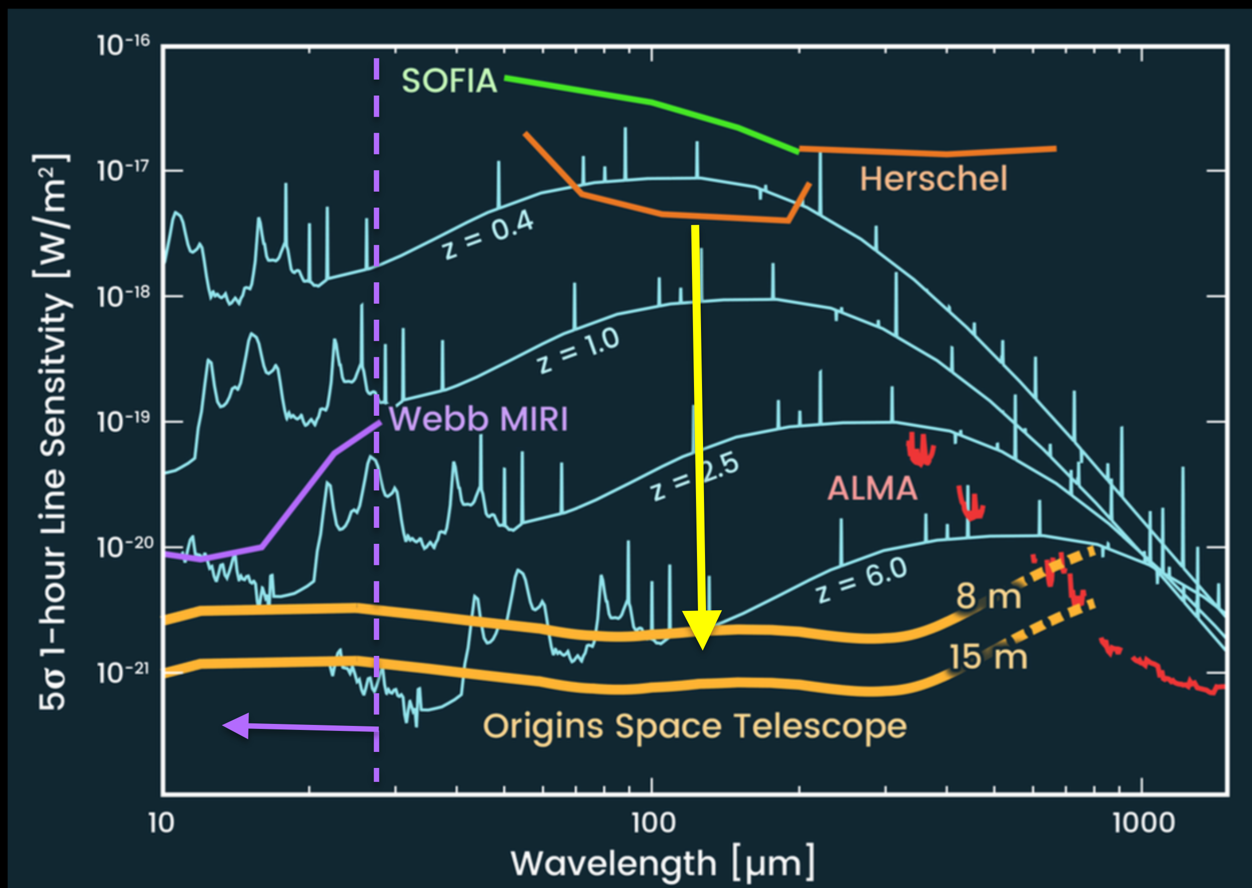
ORIGINS Space Telescope

Technical Definition

Potential Wavelength Coverage from 5 µm–1 mm



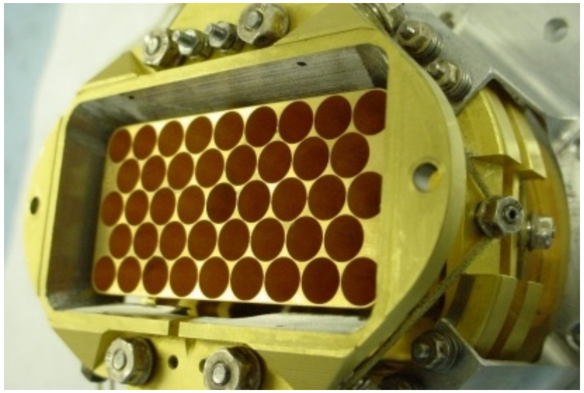
OST vs Herschel:

~10x gain from aperture

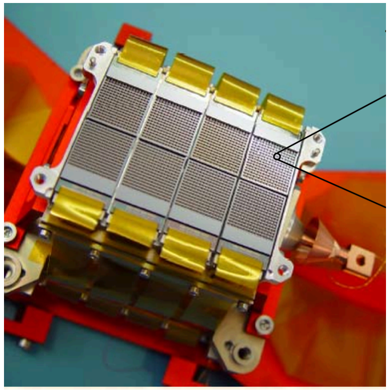
Remaining gain from lower back-ground with 4K telescope

OST vs Herschel: Detectors

- **Herschel used arrays of a few hundred to a few thousand of detectors, and warm telescope, but had very high science return**



Herschel/SPIRE Ge bolometers



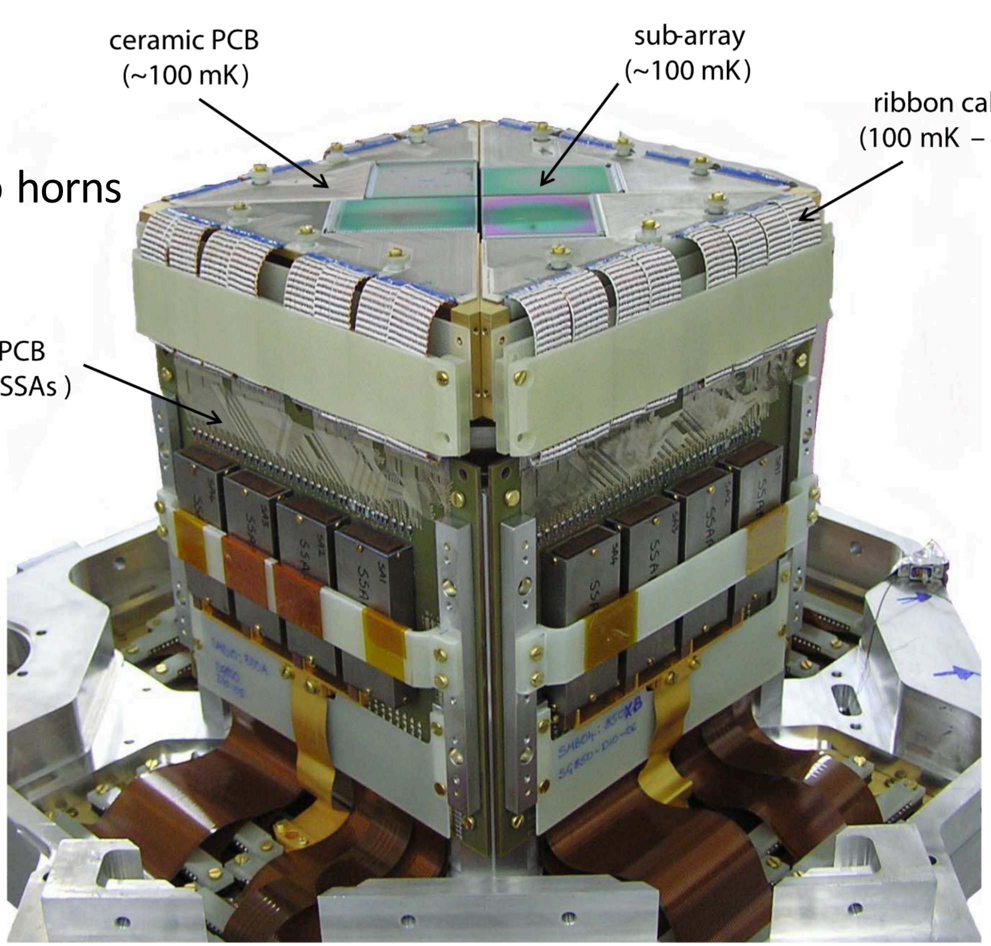
Herschel/PACS Si bolometers

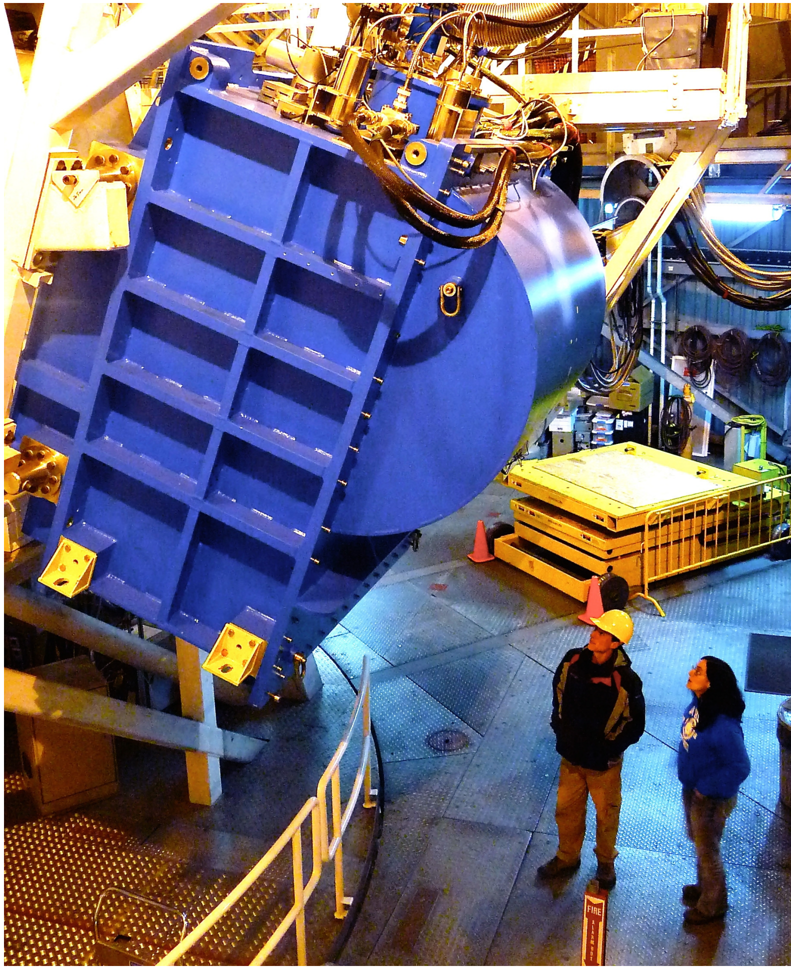
PACS blue channel (90 μm)
32 x 64 pixels
8 subarrays, 16x16 ea.
Silicon bolometers
CMOS mux
TiN absorber

- **Origins Space Telescope will require:**
  - background-limited imaging & spectroscopy on a ~4 K space telescope
  - 100 to 1000x more detectors
  - 100 to 1000x better detector sensitivity
- **Superconducting detectors are poised to meet this challenge**
  - #1 technology priority for OST (Staguhn, 1/3/17 presentation)

SCUBA 2: superconducting TES bolometers with 32:1 multiplexed SQUID readout

no horns

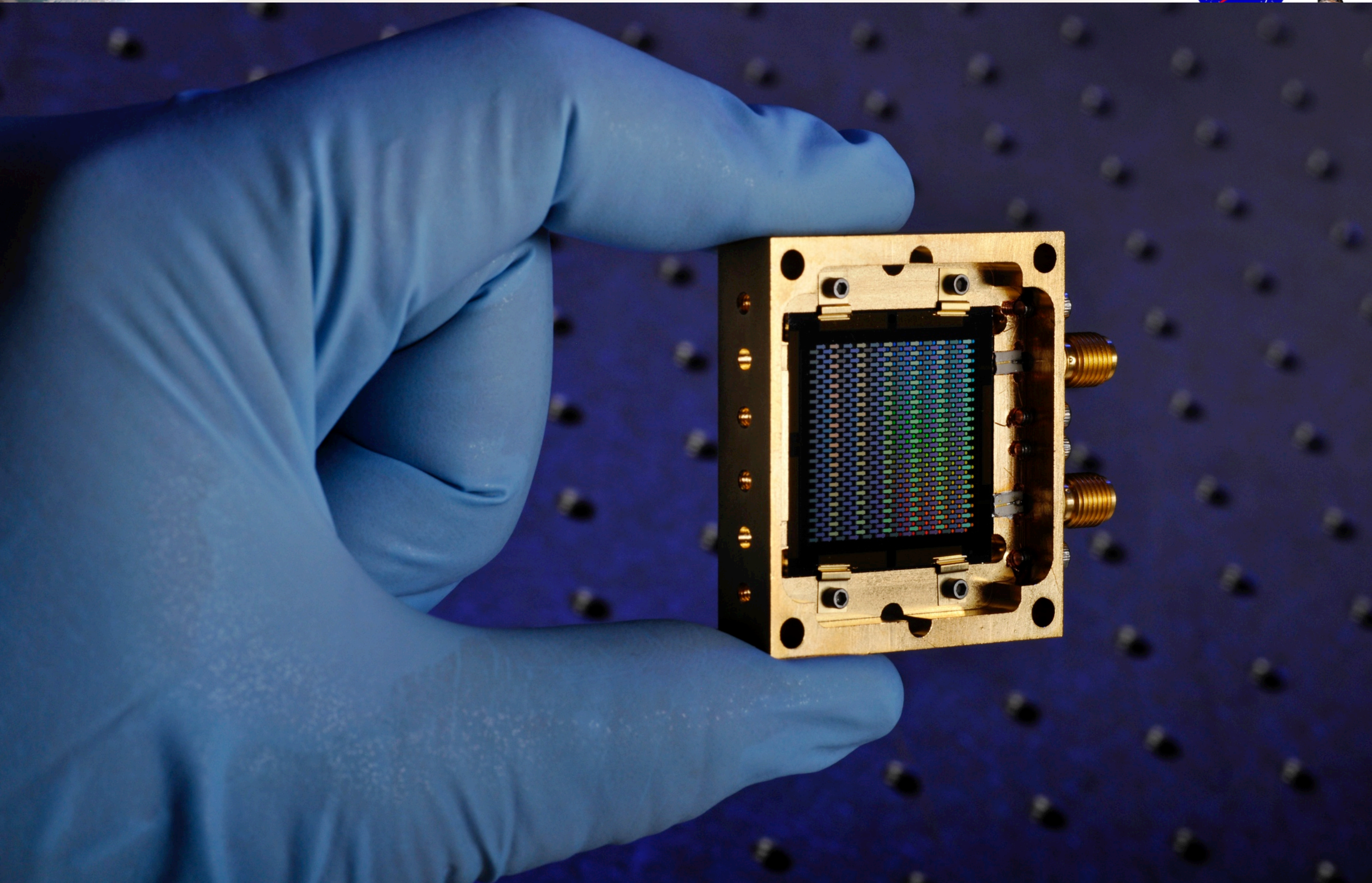




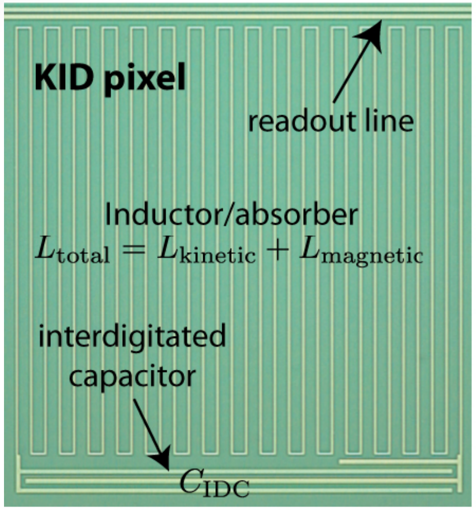
5120 pixels per band, 100 mK, TES/SQUID TDM
NEP ~ low 10^{-16} W $Hz^{-1/2}$

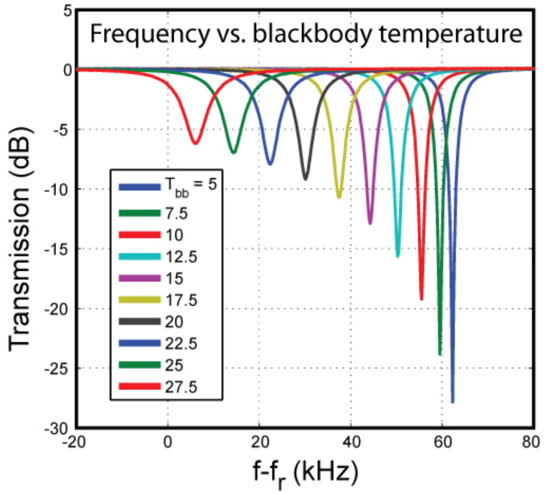
Holland et al. 2013

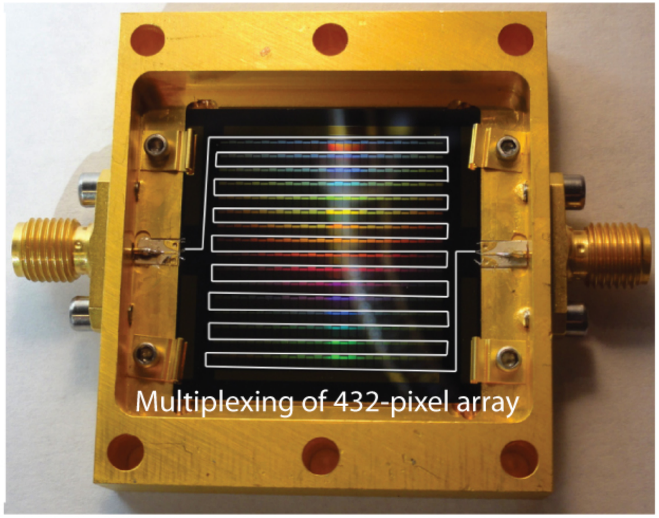
MAKO: 484-pixel, 350 μm kinetic inductance detector array (1000:1 mux density)

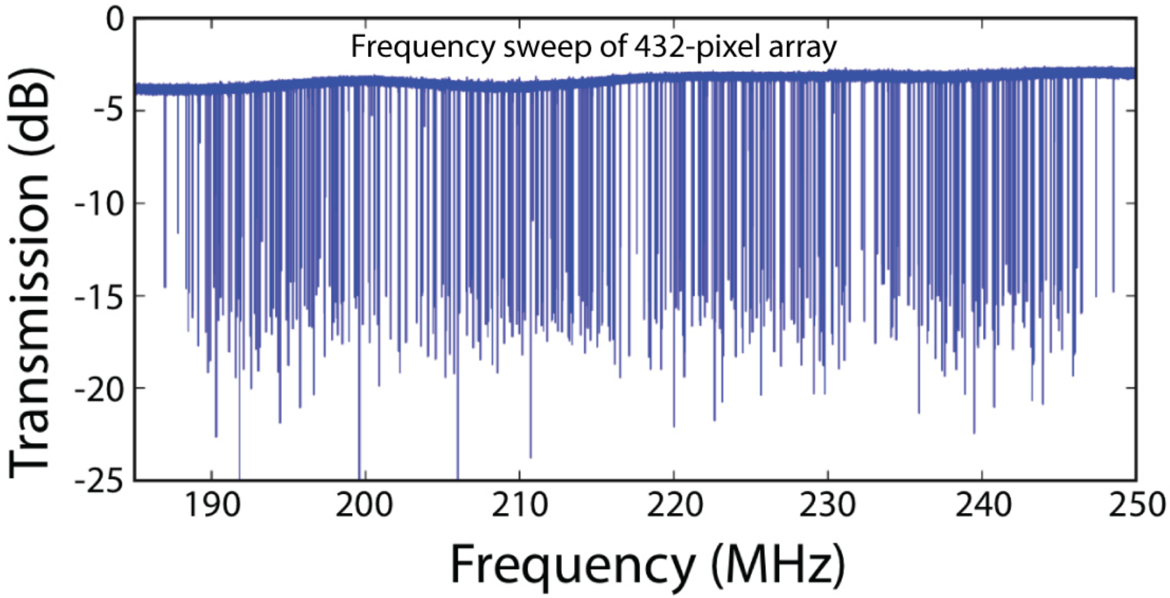


Basic Concept



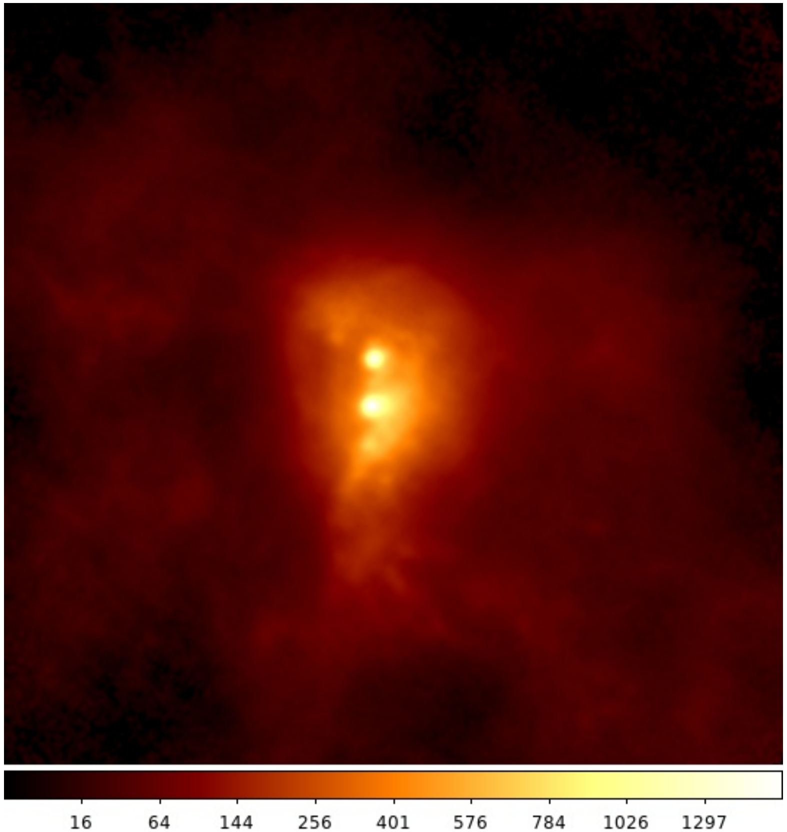




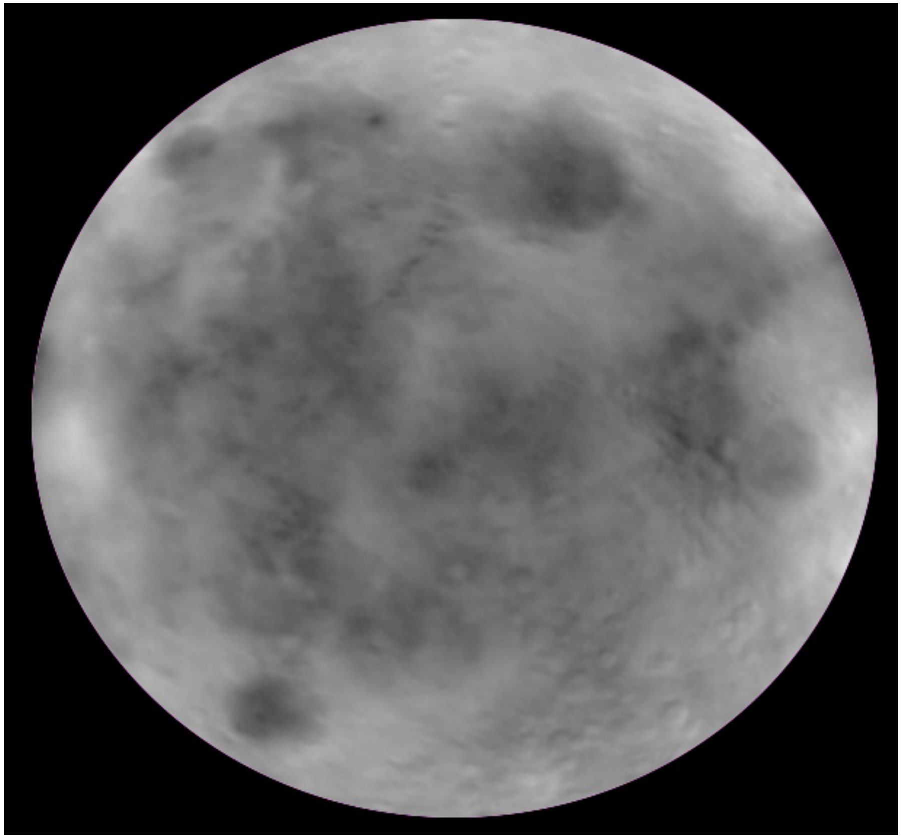


CSO Deployment

MAKO at the CSO

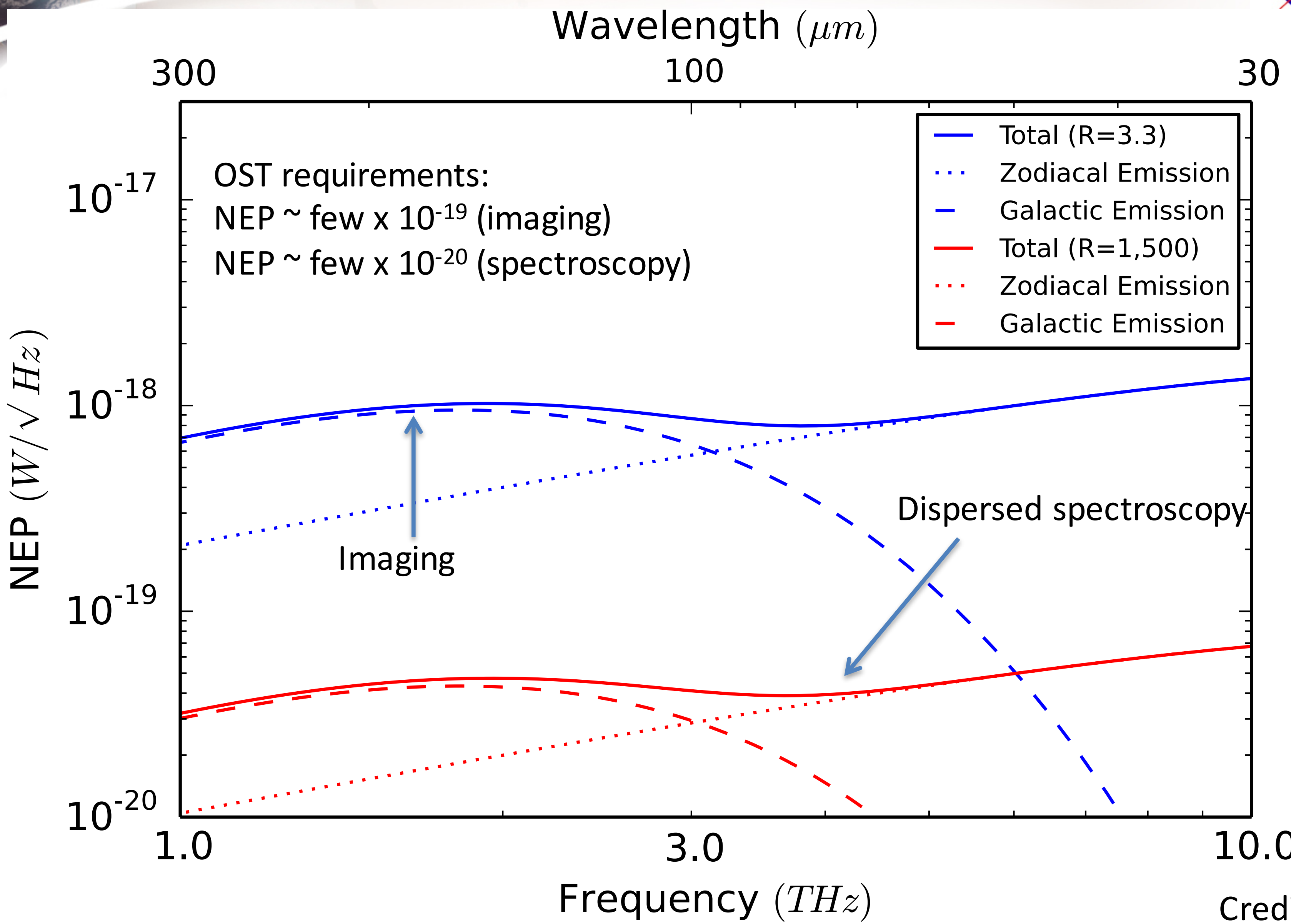


Sgr B2



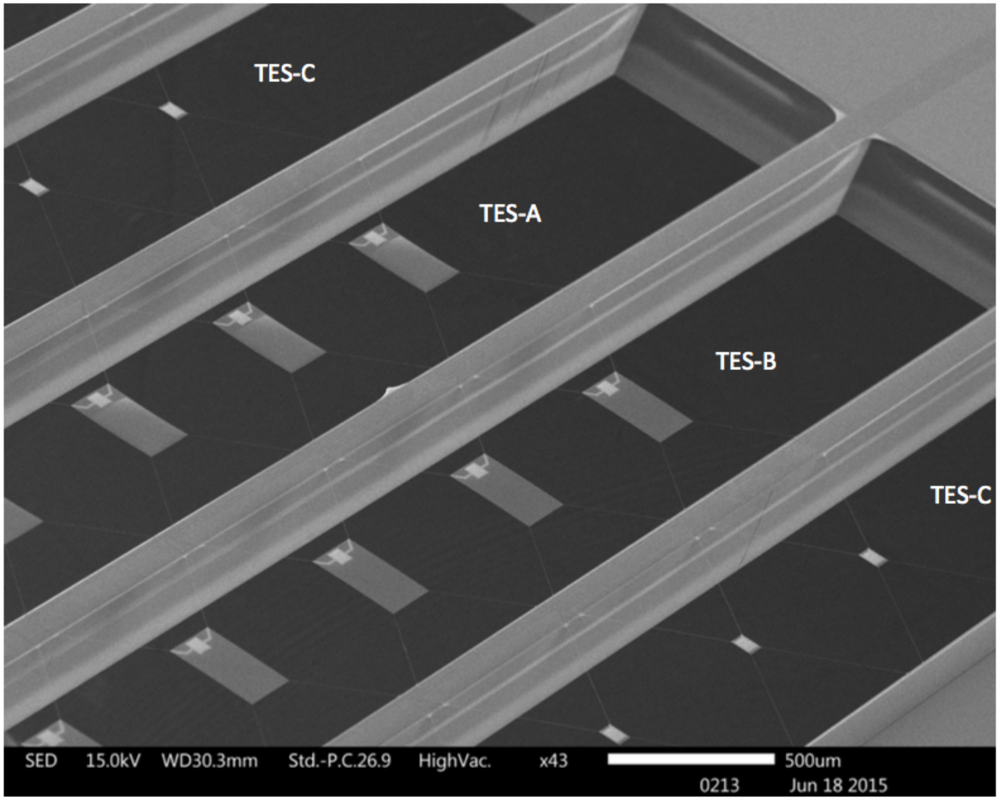
Moon

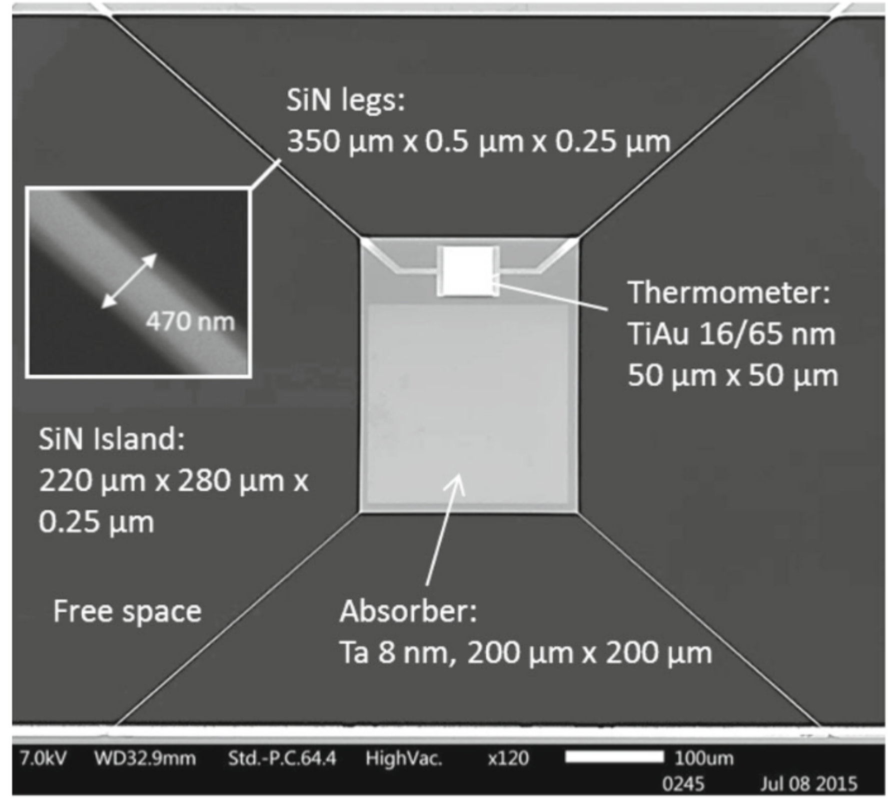
Backgrounds for Cold Space Telescope



Credit: J. Glenn

SAFARI TES detectors
(SRON, Cambridge et al.)

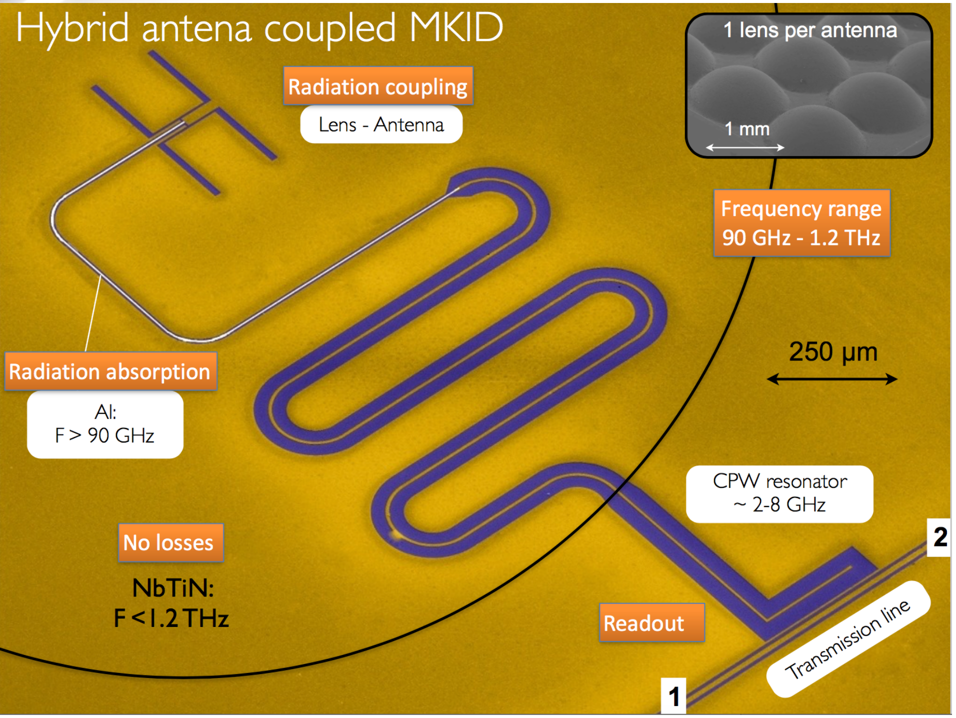


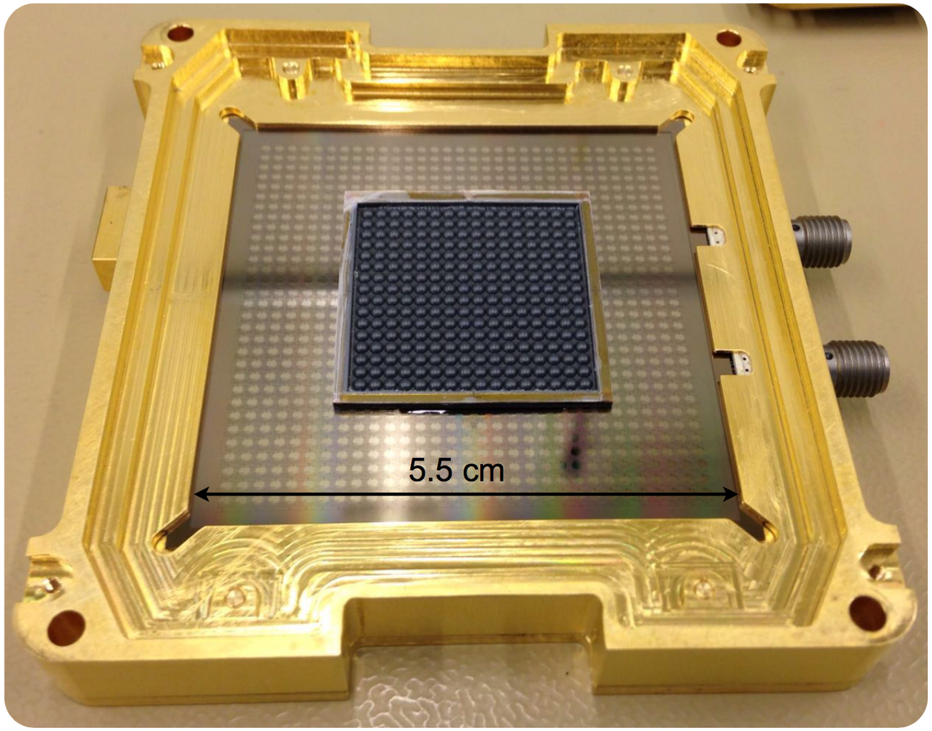


NEP ~ 2 x 10^{-19} W/Hz$^{1/2}$
Khosropanah et al. 2016

132-pixel multiplexing
Hijmering et al. 2016

SPACEKIDs: SRON, Cardiff et al.
(Baselmans et al. 2016)





NEP ~ 3 x 10^{-19} W / $Hz^{-1/2}$

Array size and mux factor: 961

Pixel pitch: 1 mm

Pixel yield: 85%

Optical efficiency: > 50%

Optical bandwidth: 1 octave

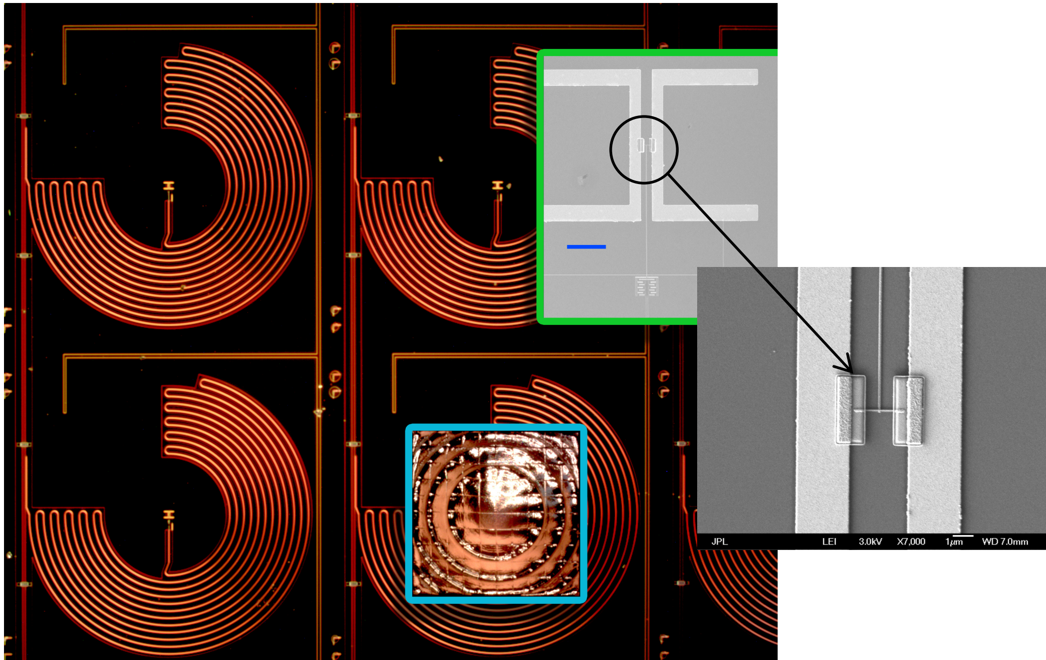
Dynamic range: > 1000

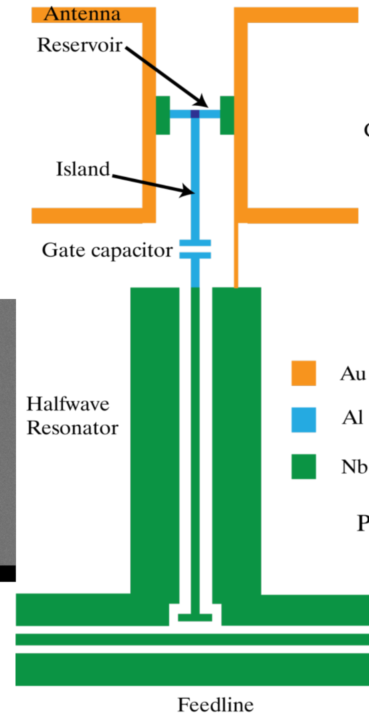
Electrical bandwidth: > 100 Hz

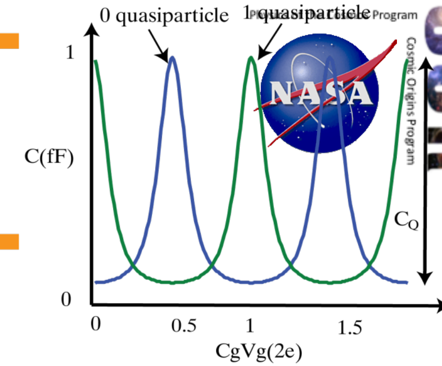
Electrical crosstalk: < -30 dB

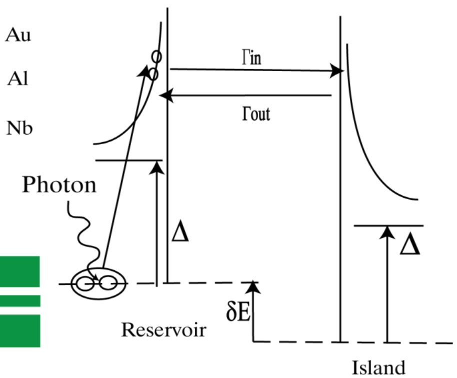
Cosmic ray deadtime: ~20% (improvements underway)

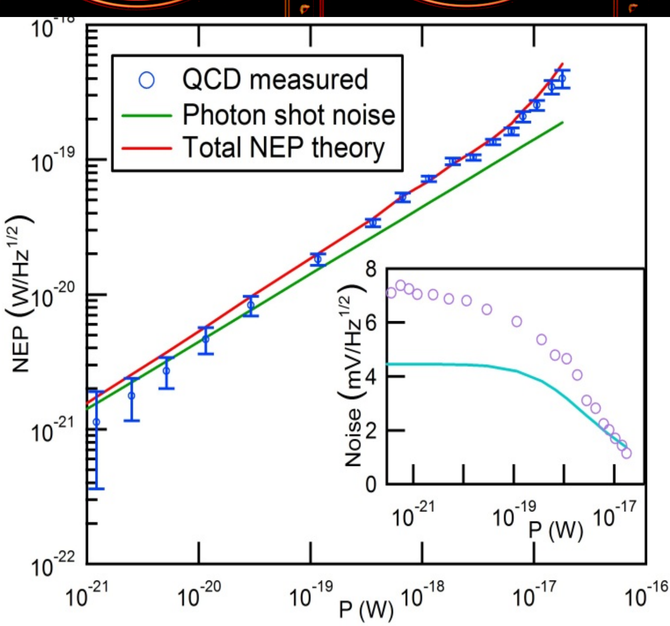
QCD: The Quantum Capacitance Detector

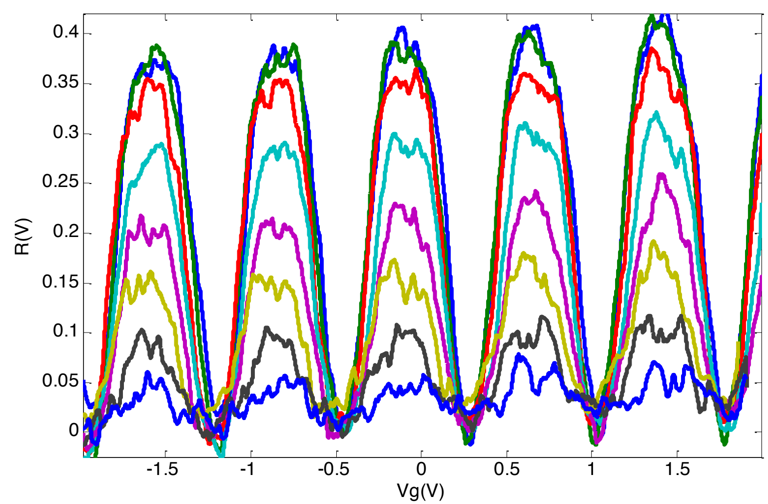






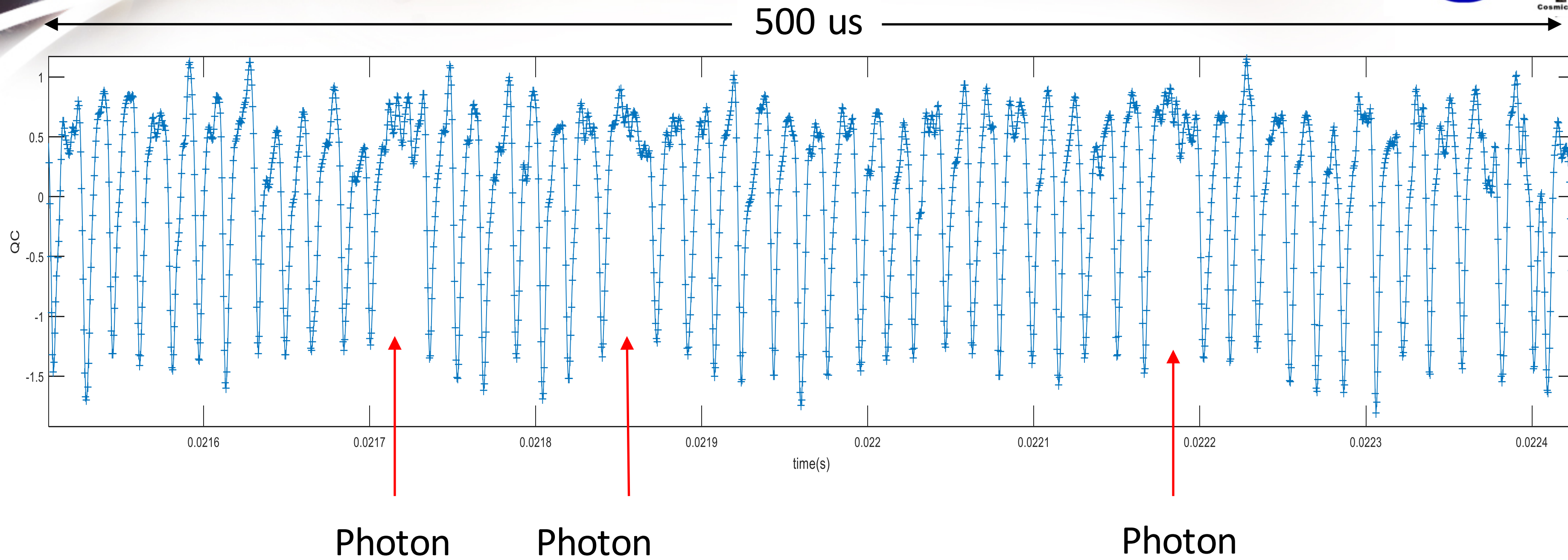






Credit: P. Echternach / JPL

QCD: Far-infrared photon counting

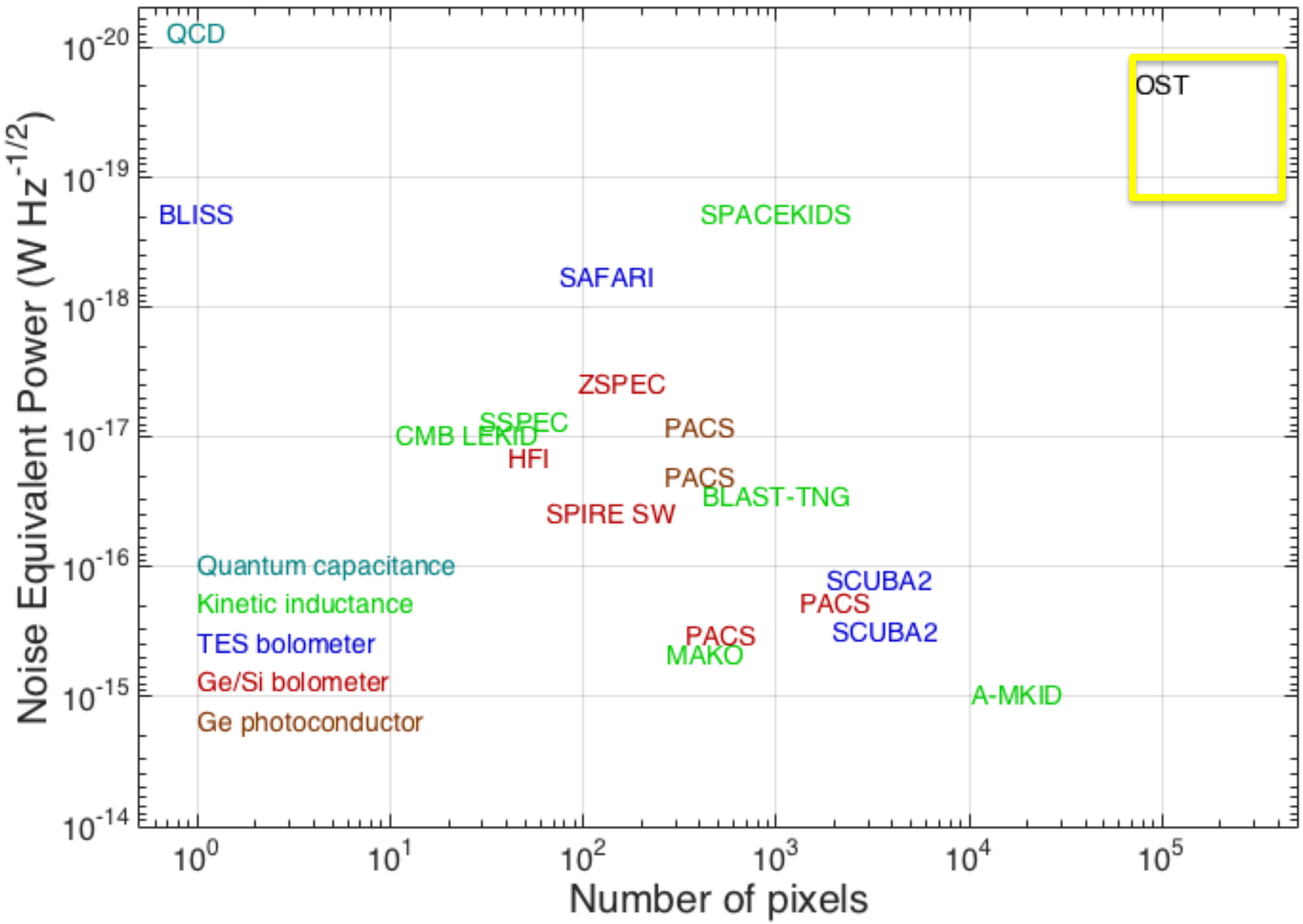


- Sweep rate ~ 22kHz spanning 4 Quantum Capacitance Peaks => effective sweep rate ~ 88kHz
- Should block background tunneling while still allowing tunneling due to single photon absorption
- Raw QC time trace should be absolutely periodic
- Gaps are due to high tunneling suppressing the Quantum Capacitance signal, due to photon absorption.

Photon counting not required for OST science, but does offer some system-level advantages: *1/f noise not an issue, * low NEP strictly speaking not required.

Credit: M. Bradford, P. Echternach

Detectors: OST's #1 Technology Challenge

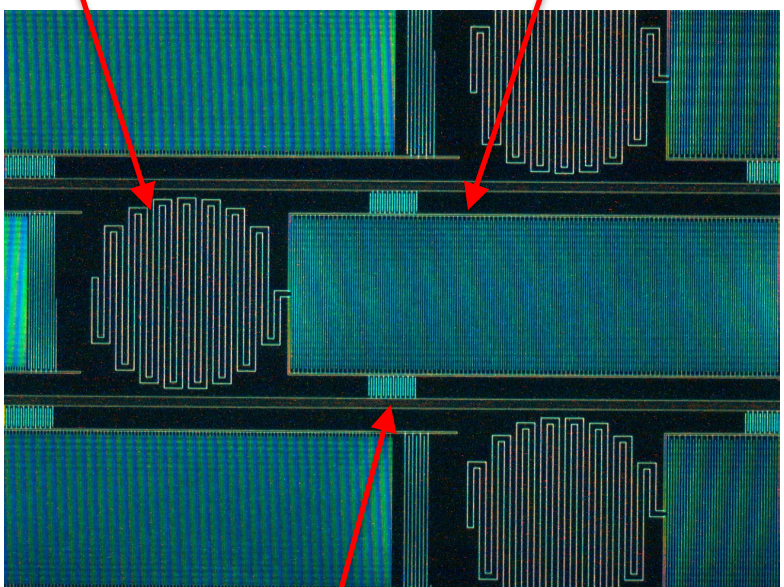


SUMMARY

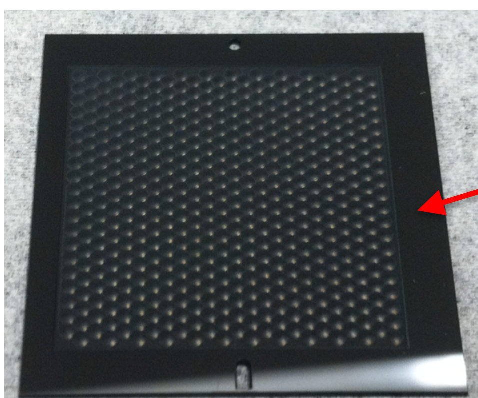
- **OST's detector technology challenges:**
  - Scalability to detector counts > 10^5
  - NEP in the 10^{-19} to 10^{-20} W $Hz^{-1/2}$ range
- **These requirements have been demonstrated individually**
- **Very good prospects for meeting all simultaneously**
  - through some combination of concepts explored to date
- **Will require focused R&D program**

BACKUP CHARTS

Small-volume absorber-coupled KIDs



Detector pitch: 1 mm



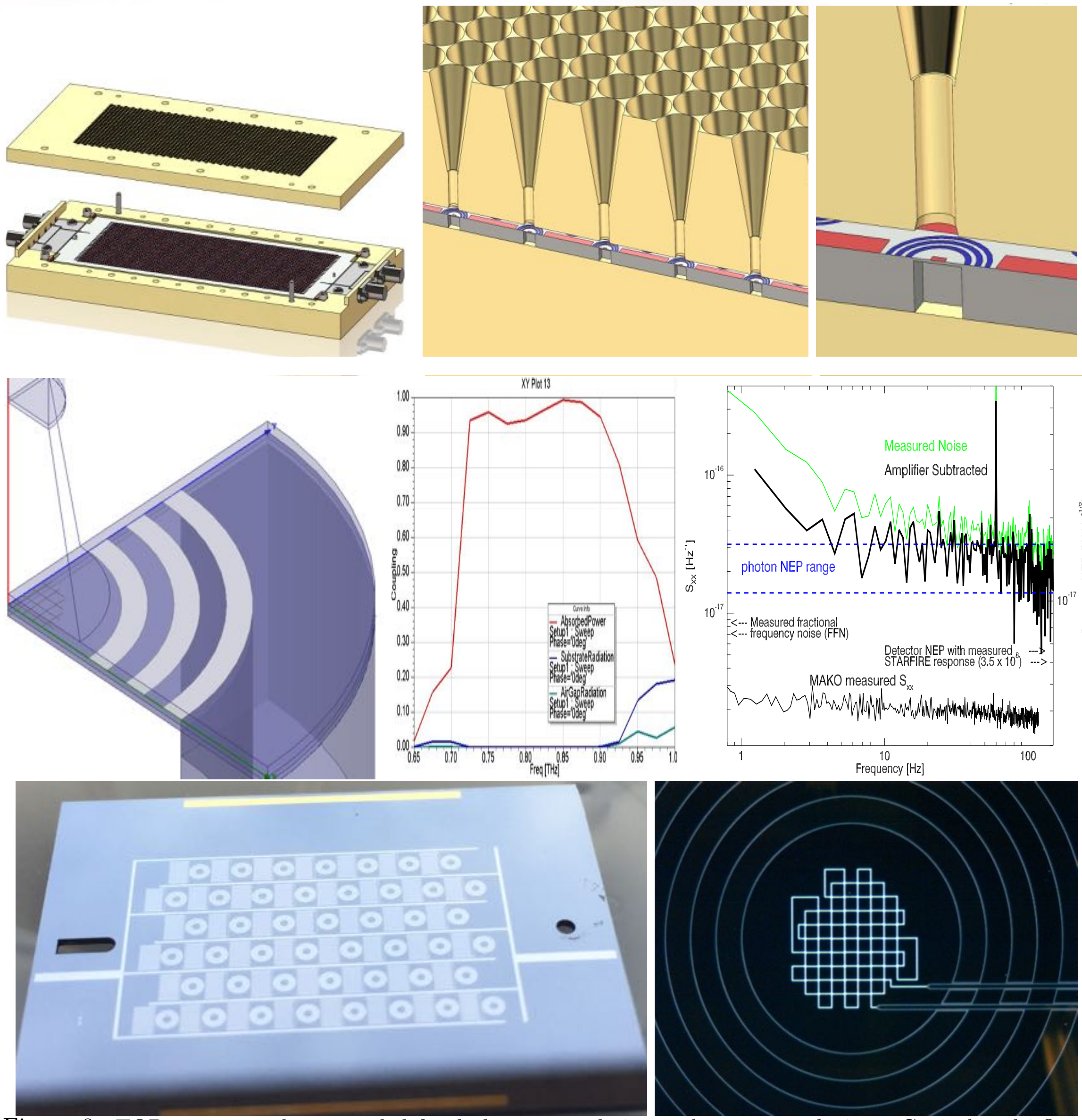
Why this architecture?

- Low volume inductors
  - ✧ Width: 150 nm
  - ✧ Thickness: 20 nm
  - ✧ Al: low resistivity ➔ Good optical absorption with a low absorber volume
  - ✧ Lens coupling ➔ Minimize inductor area, allow for IDCs
- Low f_0: few x 100 MHz
- τ_{qp} ~ 1 ms for Al
- **Challenge:** High yield?

JPL / CIT / U. Colorado
J. Glenn+ SPIE 2016

Follow-on project: ICarIS

- Balloon payload, proposed to NASA
- C^+ at 240-420 μm
  - z = 0.5-1.5
- U. Penn: Aguirre, Devlin (integration, gondola)
- JPL/CIT: Bradford, Hailey-Dunsheath (detectors - low-volume Al KIDs)
- U. Arizona: Marrone (telescope)
- Illinois: Vieira (optics)
- Chicago: Shirokoff (detector testing)
- ASU: Groppi, Mauskopf (readouts, machining)



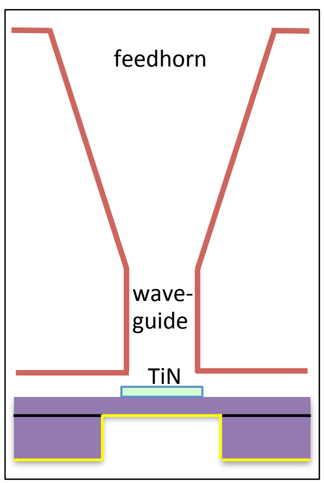
NIST National Institute of Standards and Technology U.S. Department of Commerce

Photon-noise limited sensitivity in MKIDs at 250 μm

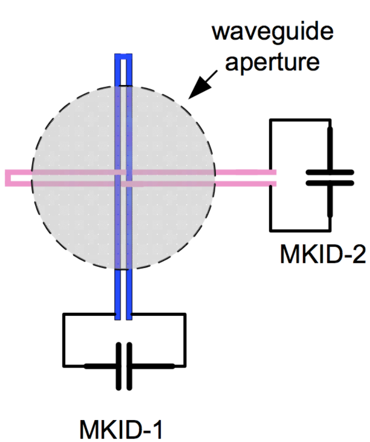
in development for BLAST-TNG, a balloon-borne polarimeter

detector development is a collaboration between NIST, UPENN, ASU and Stanford

Feedhorn-coupled MKID concept

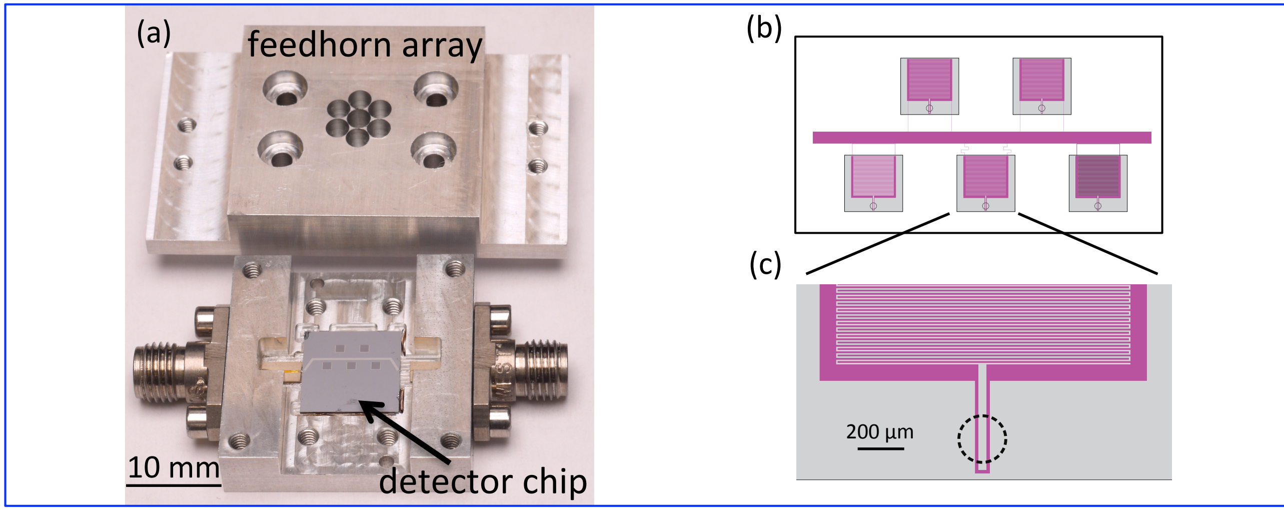


dual-polarization sensitivity within one spatial pixel

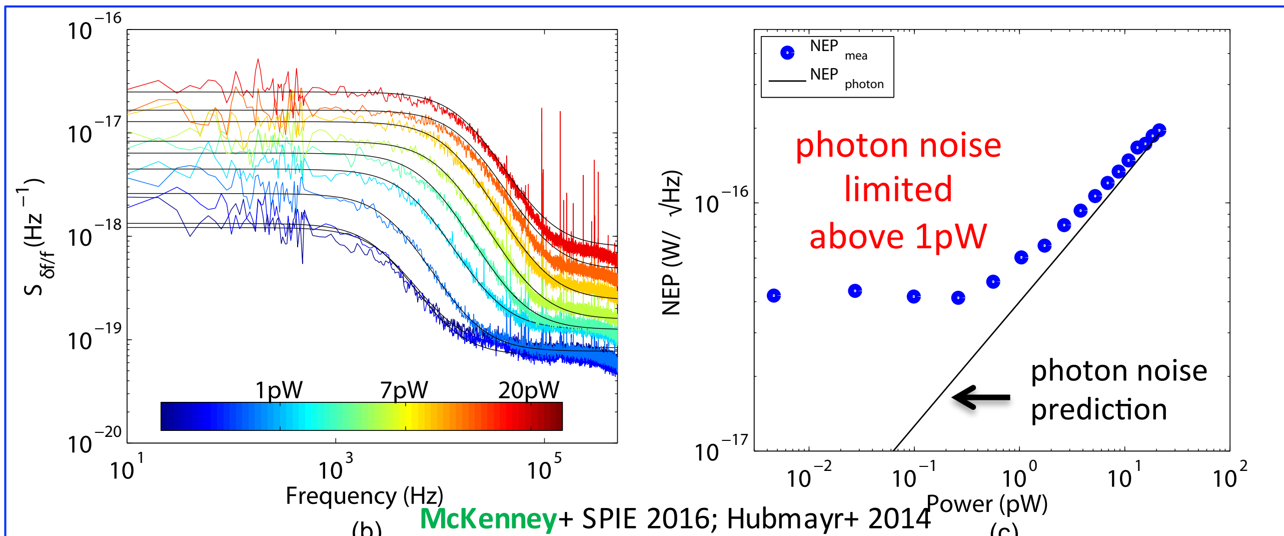


Experimental package

3000 pixels



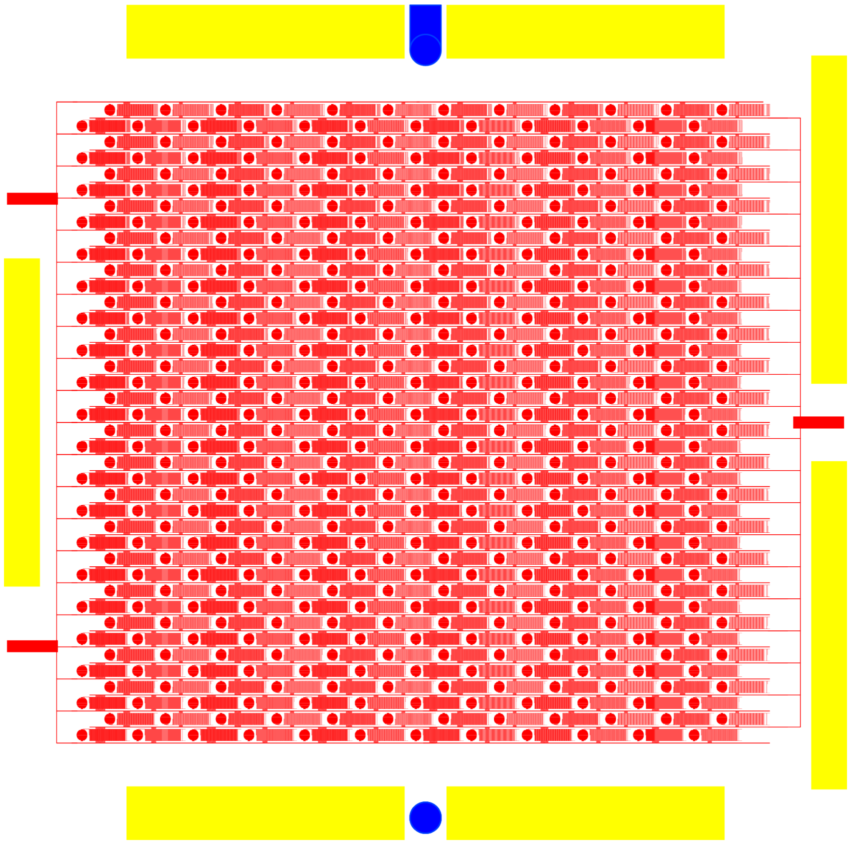
Sensitivity to variable temperature thermal load

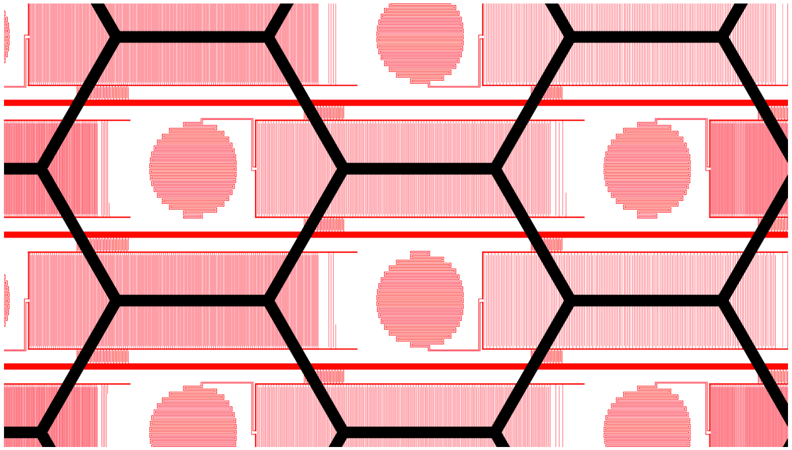


McKenney+ SPIE 2016; Hubmayr+ 2014

2G array layout

- 468 pixel array
- Gold for thermalization
- Holes for pin alignment to microlens array





- Hexagonal lattice aligns with microlens array on back side of

TiN 3G: Dual Polarization