MEC' Prime: The Next Generation of High-Contrast Imaging with the MKID Exoplanet Camera

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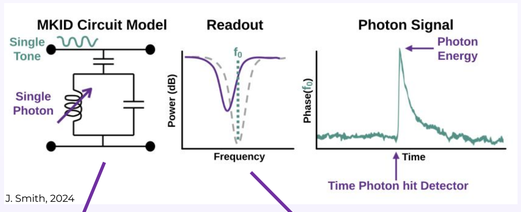
What is an MKID?

- → **Energy resolving**
- → Photon counting
- → **No dark current**
- → Microsecond Timing Resolution
- → **No read noise**

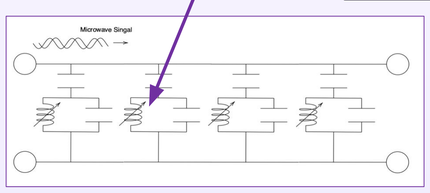
- ❖ Operate cryogenically (<1K)
- ❖ Require complex read out electronics
- ❖ Niche hardware
- ❖ Effective at imaging faint objects

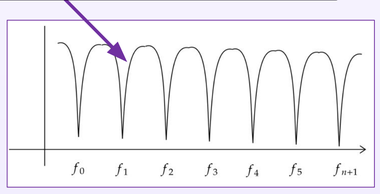


J. Smith, 2024

$$f_0 \propto \frac{1}{\sqrt{LC}}$$

MKIDs can be multiplexed into an array, 1000s of pixels can be read out across a single feedline





New MKID Array

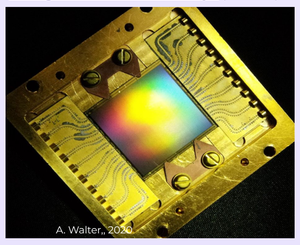
* All experimental fabrication and R&D performed at UCSB Nanofabrication

Anti-reflection Coating → **Double** QE (~70% entire passband)

Airbridges → Reduce phonon loss → **Double** spectral resolution

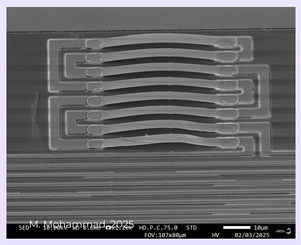
Joint UCSB and Lincoln Labs Device Fabrication → 97% Pixel Yield (**40% improvement**)

Original MEC Array (2018)



- •**Spectral R~5-7**
- •800-1400nm
- •140x146 pixels
- •**QE ~35%**
- •JPL Microdevices Laboratory
- •10 feedlines
- •Platinum Silicide composition

MEC' Prime (2025)

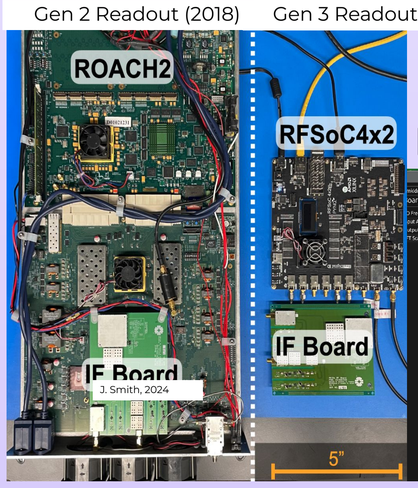


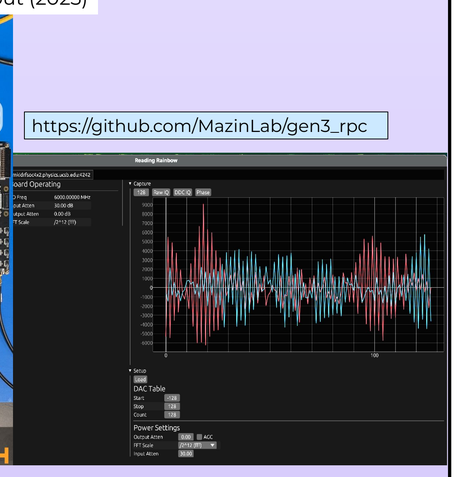
- •**Spectral R>14**
- •800-1400nm
- •140x146 pixels
- •**QE > 70%**
- •MIT Lincoln Laboratory
- •8 feedlines
- •Hafnium/Tantalum alloy

* See Michael Arena's Poster #3 "Progress Towards an Upgraded Detector Array for the MKID Exoplanet Camera (MEC')

Gen3 FPGA Readout

Gen 2 Readout (2018) Gen 3 Readout (2025)

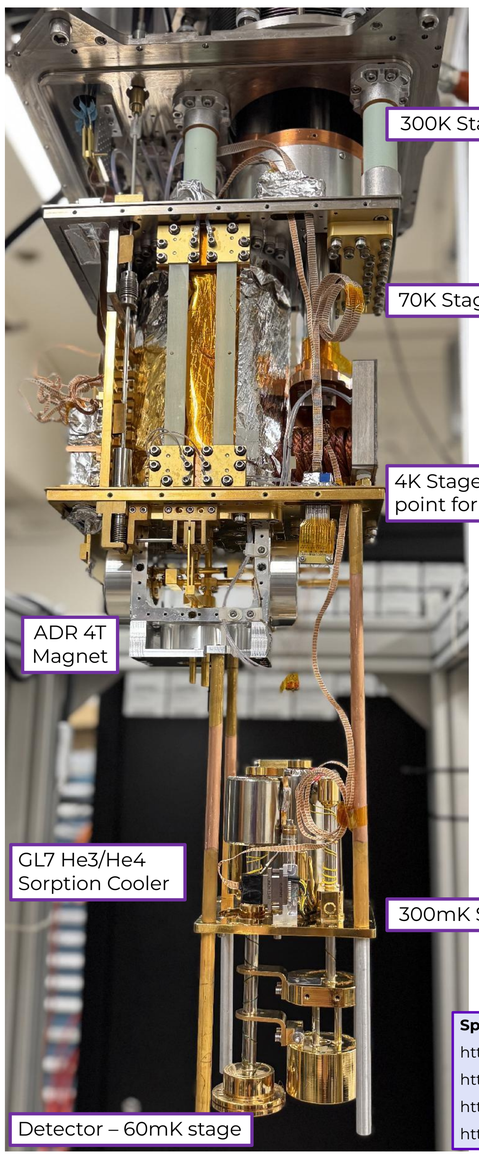




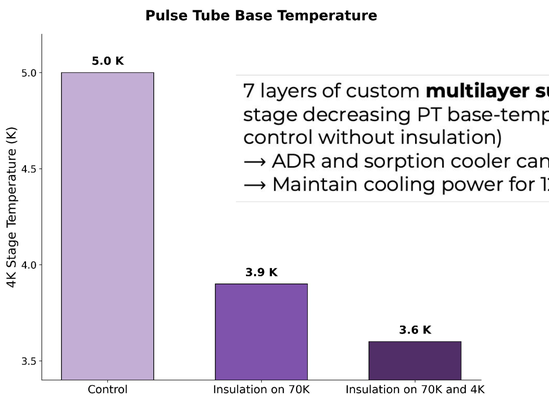
https://github.com/MazinLab/gen3_rpc

- •**10x less power usage , 10x less weight**
- •All readout boards integrated into **single CPU**
- •COTs components for reproducibility
- •Readout **twice as many resonators per board**
- •Open-source, user-friendly Rust GUI for readout operation

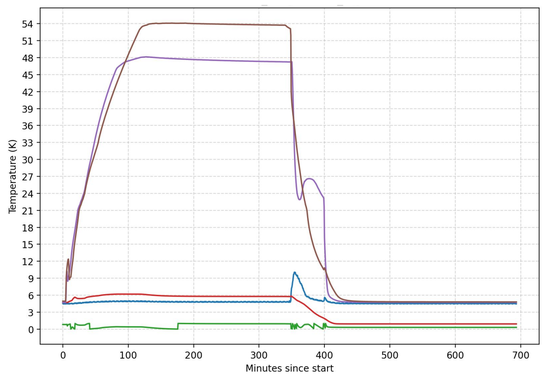
Cryostat and Hardware Upgrades



Specialized Drivers/Software:
https://github.com/MazinLab/lakeshore350-python
https://github.com/MazinLab/lakeshore370-python
https://github.com/MazinLab/lakeshore625-python
https://github.com/MazinLab/cryomech_driver



7 layers of custom **multilayer superinsulation** on 4K and 70K stage decreasing PT base-temperature by 28% (compared to control without insulation)
→ ADR and sorption cooler can launch from lower base temp
→ Maintain cooling power for 12-24 hour observation period



Adding **GL7 Sorption Cooler** (Chase Research Cryogenics) at 4K plate to cool parametric amplifiers

→ 50 μW of cooling for for 24 hours
→ Hold at 340mK for 24 hours

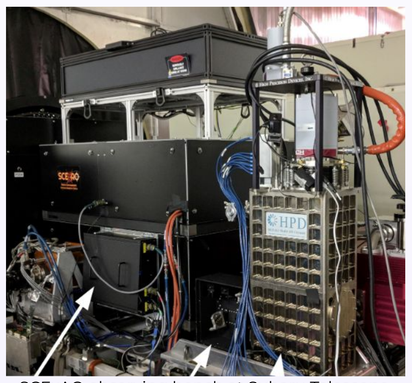
Custom Hardware:

- ❖GL7 Thermometry Loom → resistance and silicon diode thermometry reading to 200mK on 8 thermometry inputs
- ❖NbTi Flex Cable for transmitting readout signals → Extending 12 inches
- ❖Custom gold-plated mounting hardware for sorption cooler, device stage, and ADR cold head
- ❖High-current 4T magnet leads for feedback loop between magnet power supply and temperature controller

In Progress:

- ❖ User-friendly gui for cryostat control
- ❖ Diplexer boards
- ❖ Parametric amplification boards
- ❖ Professional multilayer superinsulation to lower 4K base temp
- ❖ Optical redesign to integrate with other SCExAO modules
- ❖ RF and DC vacuum feedthrough to room temperature

MKID Exoplanet Camera (MEC) (2018-2024)



SCExAO observing bench at Subaru Telescope on Mauna Kea, HI (2018)

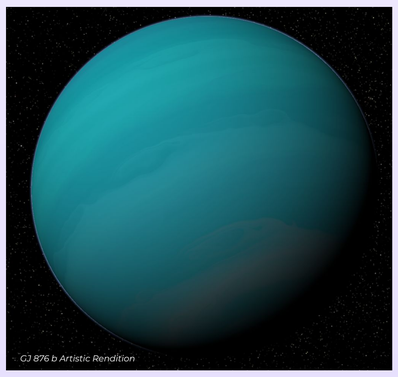
- •First permanently deployed near-infrared MKID instrument
- •20,440 pixel MKID array (R~5)
- •Discovery of 2 low-mass exoplanets
- •Observing on SCExAO bench on Subaru Telescope

Limitations:

- Low pixel yield
- Low resolution
- Extraneous noise
- Large, power hungry ROACH2-based readout system
- Dated electronics
- Inefficient data reductio
- Insufficient cryostat control software
- Lack of documentation for open-source utilization

Science Goals

- •Advance TRL of low-noise NIR detectors for future projects (HWO, TMT)
- •Utilize SSD technique with MKID camera to differentiate bright, habitable zone planets from speckles
- •**Image an exoplanet in full reflected light**
  - GJ 876b
  - GJ 896Ab
- •Open-source and COTs hardware, firmware, and software for repeatability



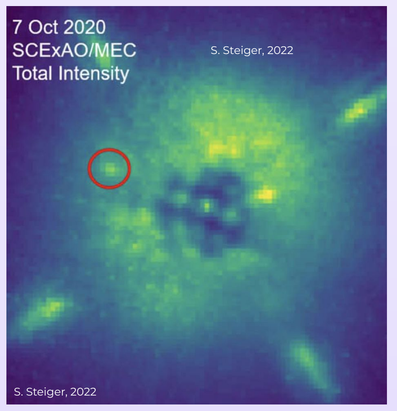


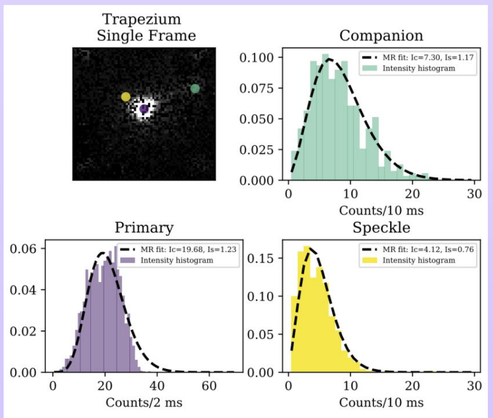
Image of HIP 109427 B taken with SCExAO/MEC in Y and J band, companion circled in red

Based [in part] on data collected at Subaru Telescope, which is operated by the National Astronomical Observatory of Japan.

Data Processing Pipeline

1. MKIDPipeline intakes data as time-tagged photon lists
2. Series of calibrations
3. User can adjust precision/ data selectivity
4. Outputs yield images, dithers, short videos, and collection of logging files → Follow up with ADI, SDI, or custom MKID speckle correction

mkidpipeline 1.9.0
`pip install mkidpipeline`



Speckle Correction:

→ Introducing 2 forms of real-time speckle correction

1.Speckle Nulling

2.Conventional CDI

→ Optimizing post-processing speckle correction

Stochastic Speckle Discrimination (SSD)

1. Uses photon arrival times to identify and remove speckles