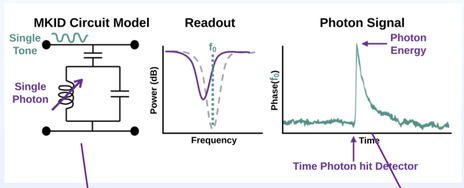
# MEC' Prime: The Next Generation of High-Contrast Imaging with the MKID Exoplanet Camera

Nikki Zivkov[1], Michael Arena[1], Aled Cuda[1], Jennifer Pearl Smith[1], Alexander B. Walter[1], Sarah Steiger[1], Olivier Guyon[2], Nemanja Jovanovic[2], Julien Lozi[2], Frantz Martinache[2], Ben Mazin[1]
University of California Santa Barbara[1], Subaru Coronagraphic Extreme Adaptive Optics (SCExAO)[2]

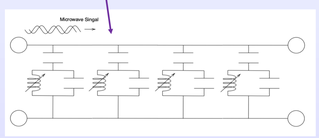
## Microwave Kinetic Inductance Detector (MKID) Operation

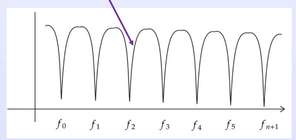



→ Energy resolving
→ Photon counting
→ **No dark current**
→ Microsecond Timing Resolution
→ **No read noise**

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

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

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## New High Resolution, High Yield MKID Array

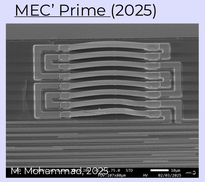
* All experimental fabrication and R&D performed at UCSB Nanofabrication

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

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

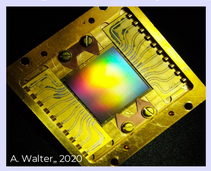
**Lincoln Labs Device Fabrication** → 97% Pixel Yield (**40% improvement**)

MEC' Prime (2025)




- **Spectral R>14**
- 800-1400nm
- 140x146 pixels
- **QE > 70%**
- MIT Lincoln Laboratory

Original MEC Array (2018)

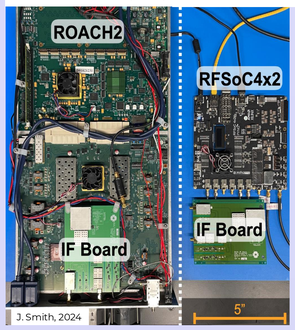



- **Spectral R~5-7**
- 800-1400nm
- 140x146 pixels
- **QE ~35%**
- JPL Microdevices Laboratory

## Smaller, Lighter, Optimized Xilinx RFSoC-based Readout System

- **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

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

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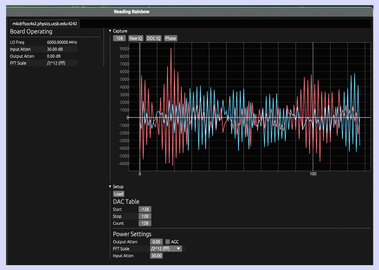
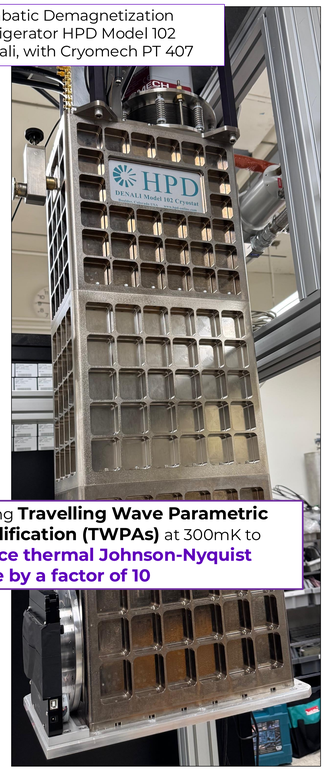
https://github.com/MazinLab/gen3_rpc



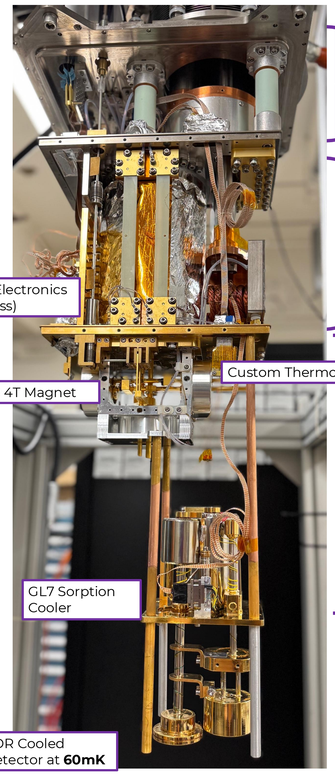

## Cryostat Hardware Upgrades

Adiabatic Demagnetization Refrigerator HPD Model 102 Denali, with Cryomech PT 407




Adding **Travelling Wave Parametric Amplification (TWPAs)** at 300mK to **reduce thermal Johnson-Nyquist noise by a factor of 10**

Interior



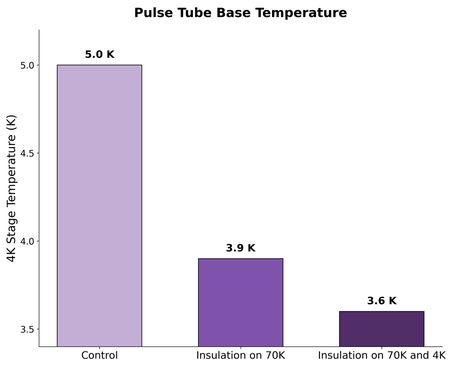

300K Stage (Room temperature)

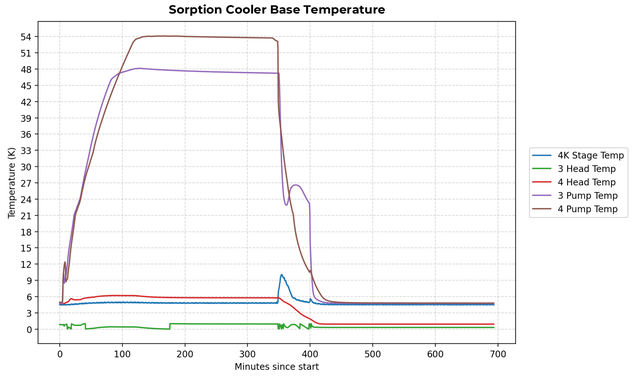
70K Stage (Cooled via PT 407)

Custom Thermometry Cabling

4K Stage (Cooled via PT 407) - launching point for ADR and GL7 sorption cooler

300mK Stage (Cooled via GL7 Sorption Cooler)




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

Adding **GL7 Sorption Cooler** (Chase Research Cryogenics) at 4K plate to cool parametric amplifiers
→ 50 $\mu$W of cooling for for 24 hours
→ Hold at 340mK for 24 hours

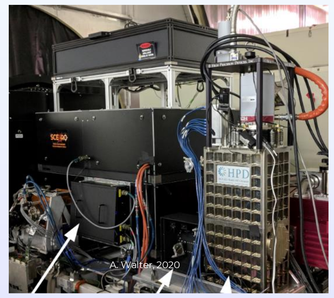
**Completed:**

- New, streamlined cabling and electronics
- Customized machined hardware
- Open-source control software for Lakeshore 350 Temperature Controller, Lakeshore 370 AC Resistance Bridge, and Lakeshore 625 Superconducting Magnet Power Supply
- GL7 sorption cooler integration

**In Progress:**

- Custom readout electronics from 300K to 60mK
- Interactive GUI for cryostat control during observation
- Diplexer boards
- Parametric Amplification
- Professional multilayer superinsulation to lower 4K base temp
- Optical redesign to integrate with other SCExAO modules

## 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

**Limitations:**

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

## Science & Technology Goals

- Advance TRL of low-noise NIR detectors for future projects (HWO, TMT)
- **First fully reflected light image of an exoplanet**
  - GJ 876b
  - GJ 896Ab
- Open-source and COTs hardware, firmware, and software to allow repeatability from other groups

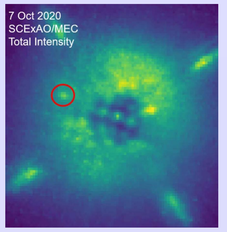
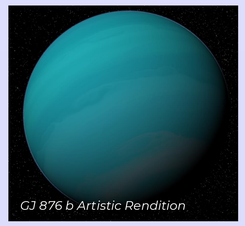



*Image of HIP 109427 B taken with SCExAO/MEC in Y and J band, companion circled in red*




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

## Open-Source Software

- Optimizing post-processing pipeline (mkidpipeline)
- Rewriting remote operations software to Linux-based OS
- Open-source library for driving cryostat control
  - Non-instrument specific

**mkidpipeline 1.9.0**

```
pip install mkidpipeline
```

https://github.com/MazinLab/lakeshore350-python

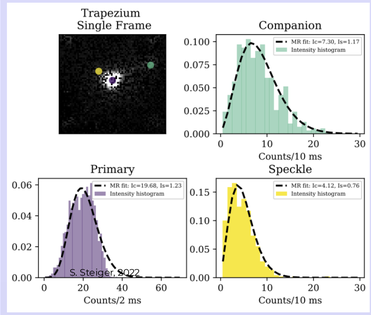
Speckle Correction:

→ Introducing 2 forms of real-time speckle correction

1. **Speckle Nulling**
2. **Conventional CDI**

→ Optimizing post-processing speckle correction

1. **Stochastic Speckle Discrimination (SSD)**
2. Uses photon arrival times to identify and remove speckles




S. Steiger, 2022