Do Microwave Kinetic Inductance Detectors (MKIDs) offer a new level of space debris identification and tracking

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Background to our involvement in SSA

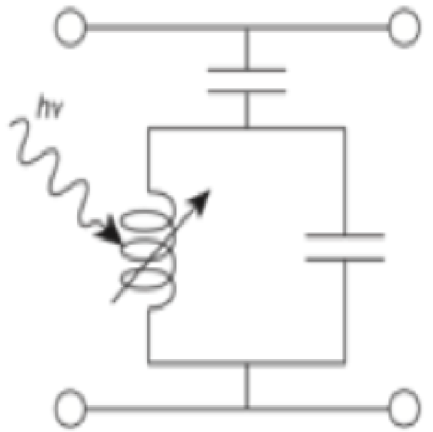
- Cryogenic single photon detectors
- Ultra Low Temperature (0.1 K) cryogenic systems for ground and space use
- Conversation with Don Pollacco on MKIDs
- Ph.D project (Saeed Vahedikamal)

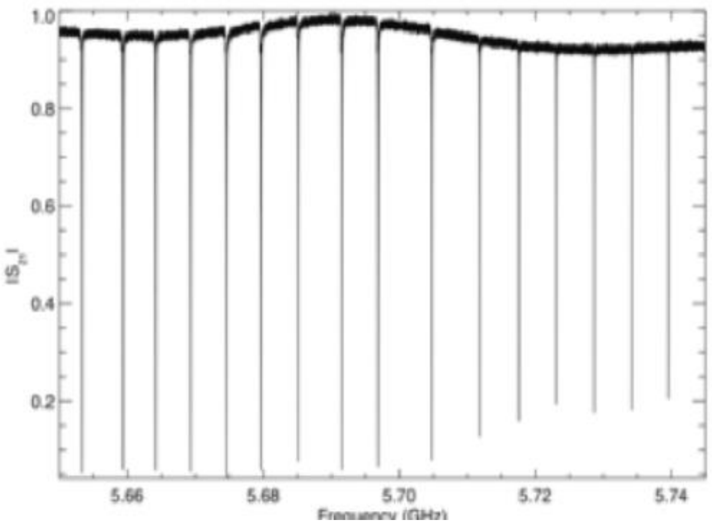
Single photon cryogenic detectors

Single photon detectors have been in development for ~30 years.

- Initially as X-Ray detectors due to the larger energy of the photon
  - X-Ray Micro-calorimeter
- ~ 20 years ago development of superconducting devices lead to optical and IR detectors
  - Superconducting Tunnel Junction (STJ)
- Difficultly with devices and low uptake on technology
  - Amplifier needed per pixel leading to limitations in array size or complicated multiplexing techniques
  - 50 - 100 mK temperature required.
- Significant development in 2005 – B Mazin Ph.D Thesis – Microwave Kinetic Inductance Detectors
  - Still 100 mK operation (MSSL focus for the last ~20 years for space use).
  - Inherently multiplex – resonant circuit
  - Significant reduction in amplifiers needed and no complicated multiplexing.

Microwave Kinetic Inductance Detector (MKID)





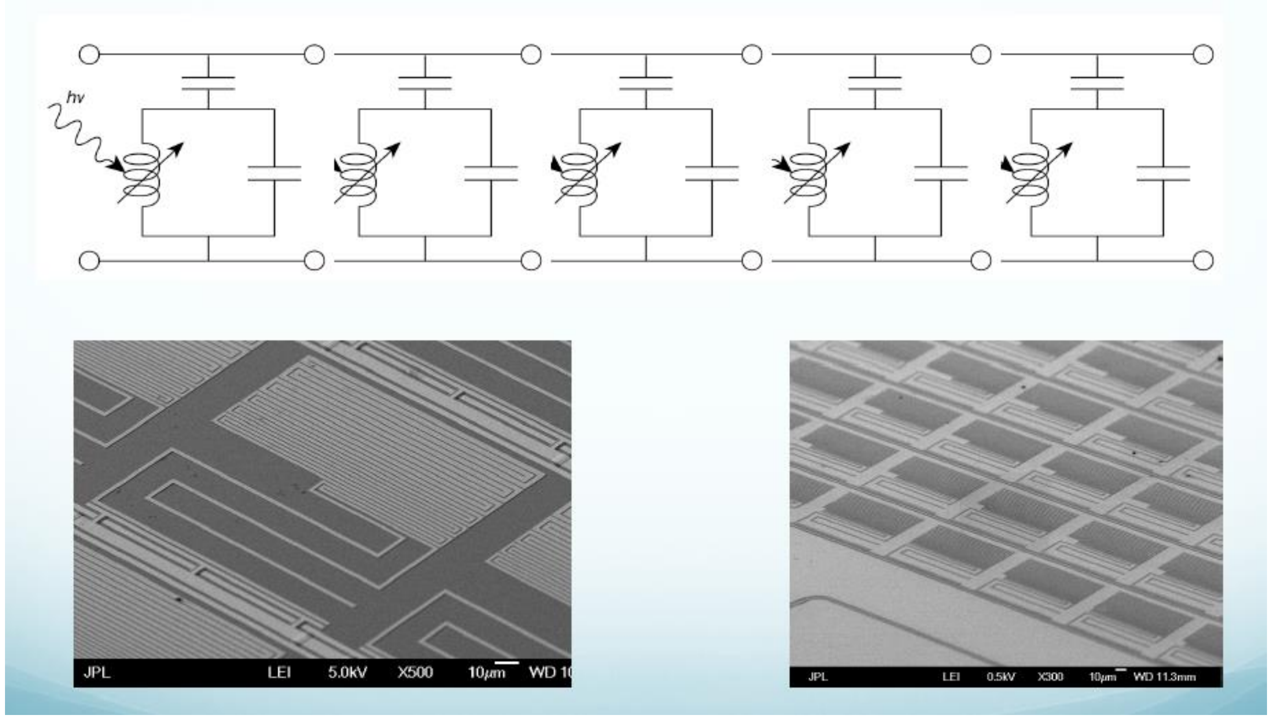
Frequency space 5.65 – 5.75 GHz. Pixel frequency spacing ~6MHz

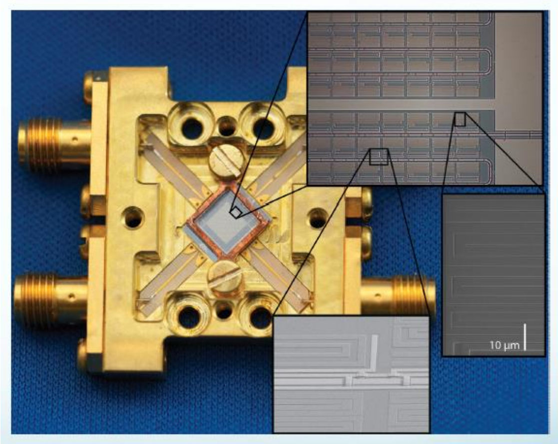
MKID pixel

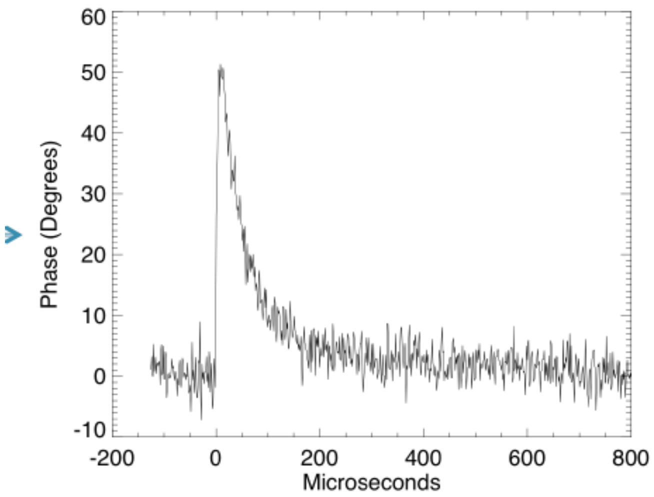
- LC resonance circuit
    - Resonance frequency set by capacitor and inductor values
    - Photon detecting part is the superconducting inductor.
- With each pixel having a different L and C value the resonance frequency can be set so that each pixel is different.
- ~ 2000 discreet frequencies within system bandwidth. This means ~2000 pixels with different resonance frequencies are readout by 1 line.
- Photon detection is via incident photon changing the inductance and thus resonance frequency.
    - Pixel biased at resonance frequency. Change due to photon is seen as a phase change.
- Pixel sensitive over the UV-Optical-IR wavelength range.

All Figures courtesy of B Mazin (UCSB)

Microwave Kinetic Inductance Device Arrays (MKID Arrays)







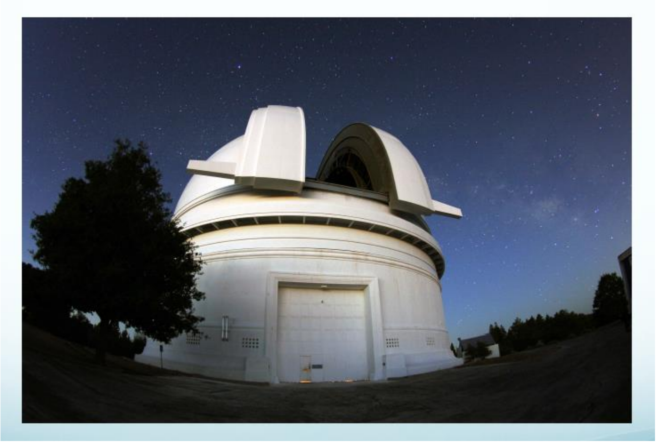
1024 pixel UV,Optical, IR MKID array
(readout via only 2 lines)

Output due to single 254 nm
(UV) photon

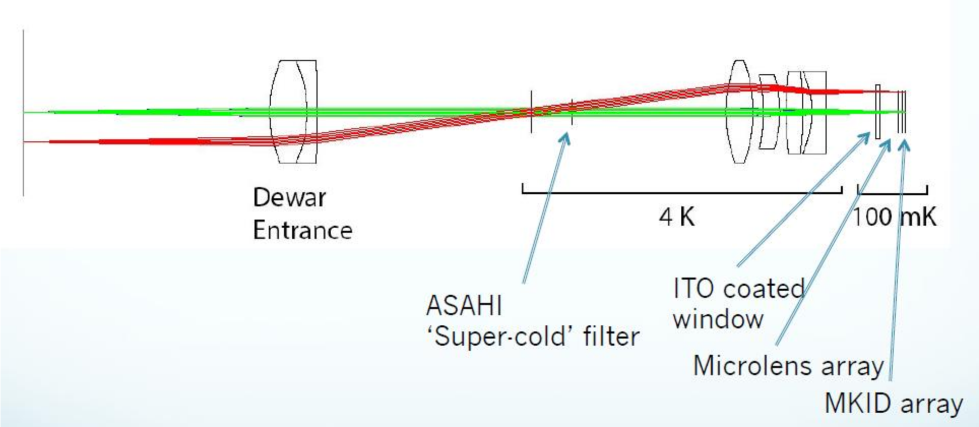
All Figures courtesy of B Mazin (UCSB)

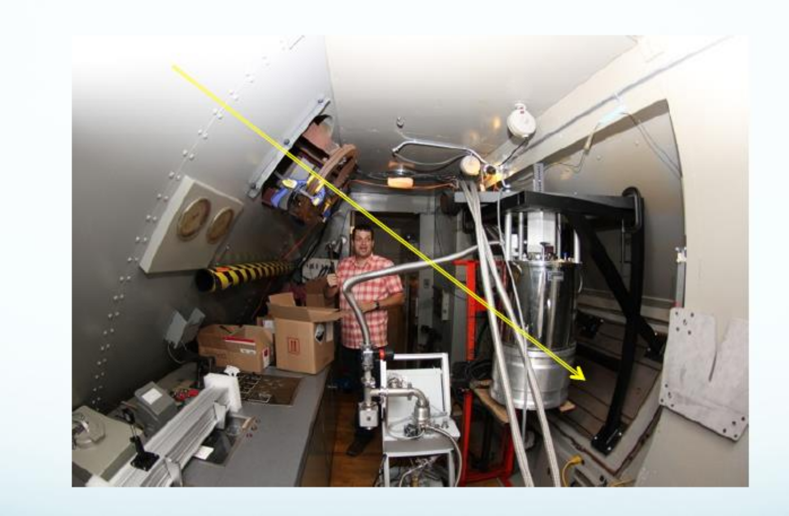
MKID arrays in use

ARCONS instrument.
Courtesy of B Mazin (UCSB)



Very simple optical system
No filter wheel needed

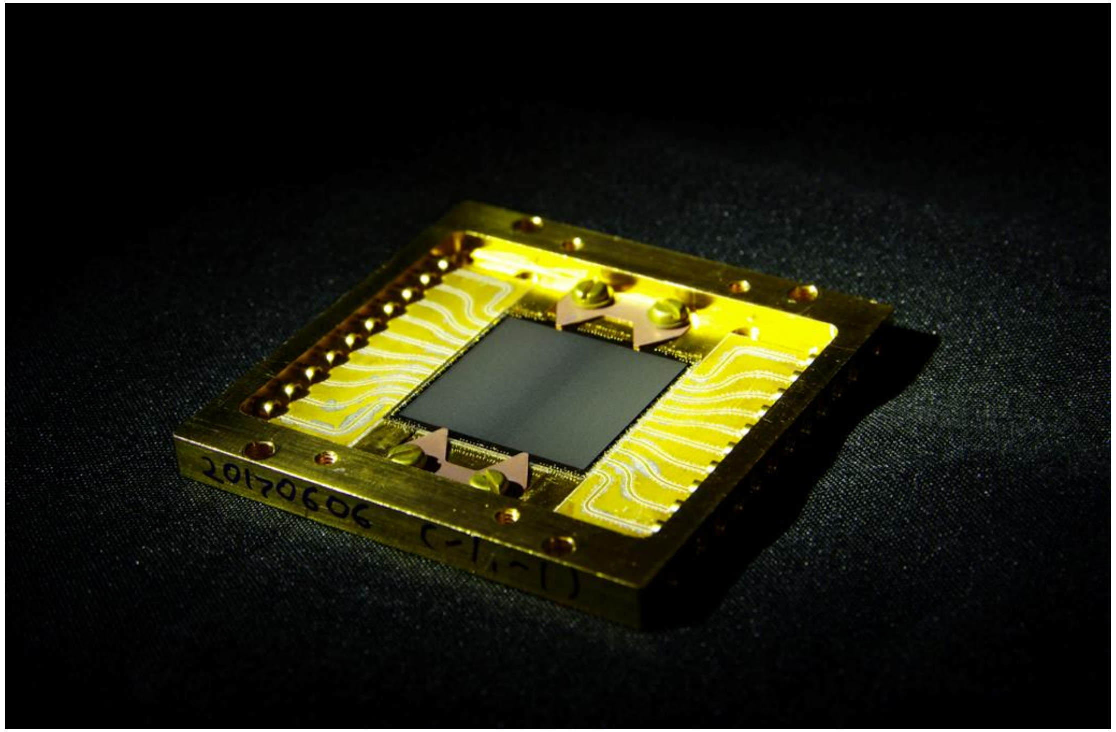




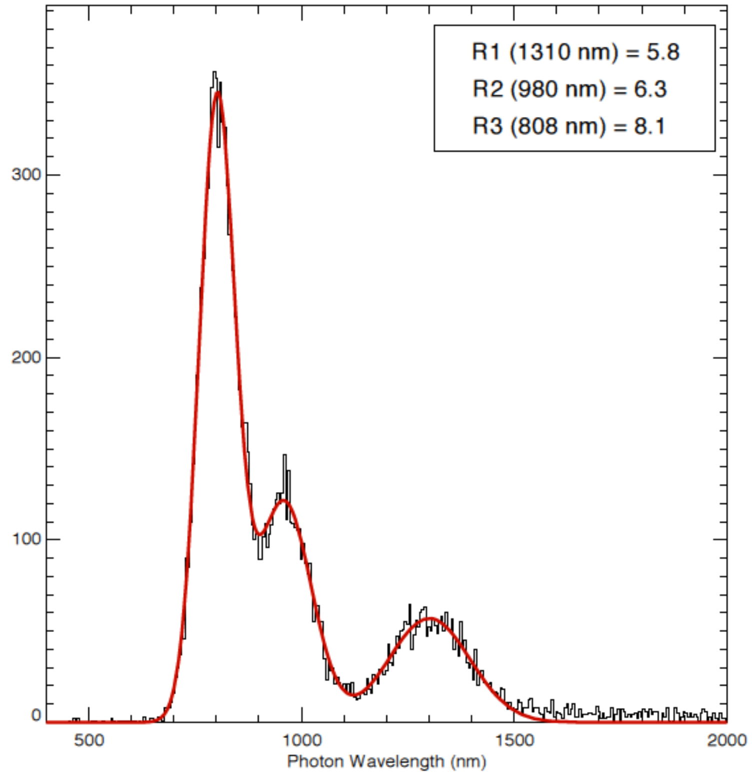
Camera generates 4 dimensional data space:

- 1st & 2nd dimensions – spatial
- 3rd dimension – spectral per pixel
- 4th dimension – Time (µ seconds) per pixel

Current status



20, 440 pixel MKID array



The measured response of an MKID pixel to illumination with 3 different lasers at 808, 980, and 1310 nm.

courtesy of B Mazin (UCSB)

MKID application to space debris

Each pixel is part of a 4 dimensional data space

- 2d special
- Spectral
- Time

Can we exploit these proprieties

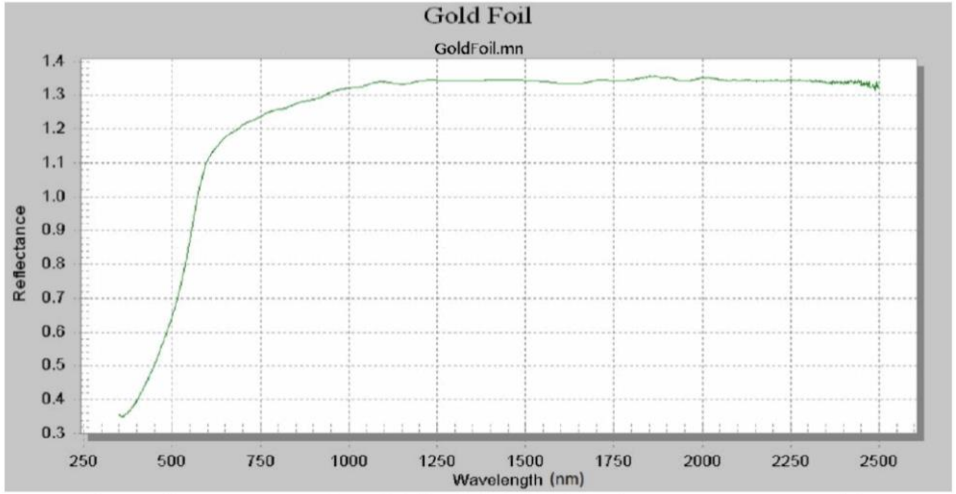
– For each pixel of array

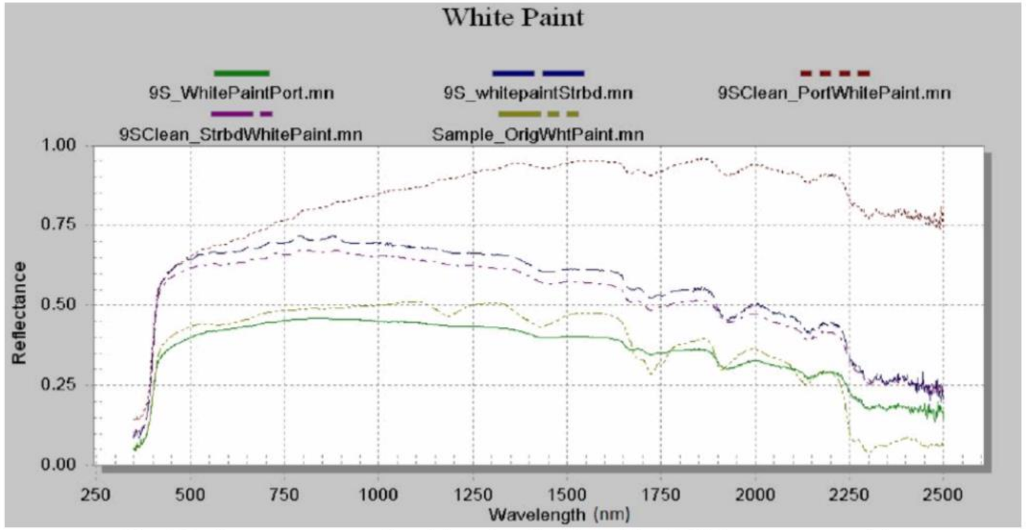
  - Single photon sensitivity to see fainter debris.
  - Spectral sensitivity – spectral signature of the piece of debris
  - Time sensitivity - micro second time tagging of each photon.

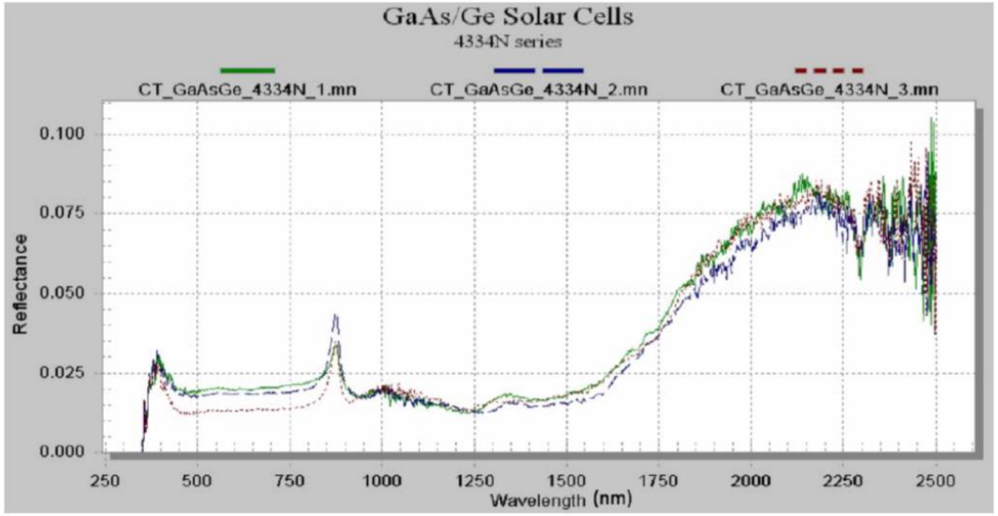
$\Rightarrow$ Temporal spectral signature.

Could this result in each piece of observed debris being uniquely identified by its temporal spectral signature $\Rightarrow$ Easier to track with multiple observing sites?

Spectral signature example







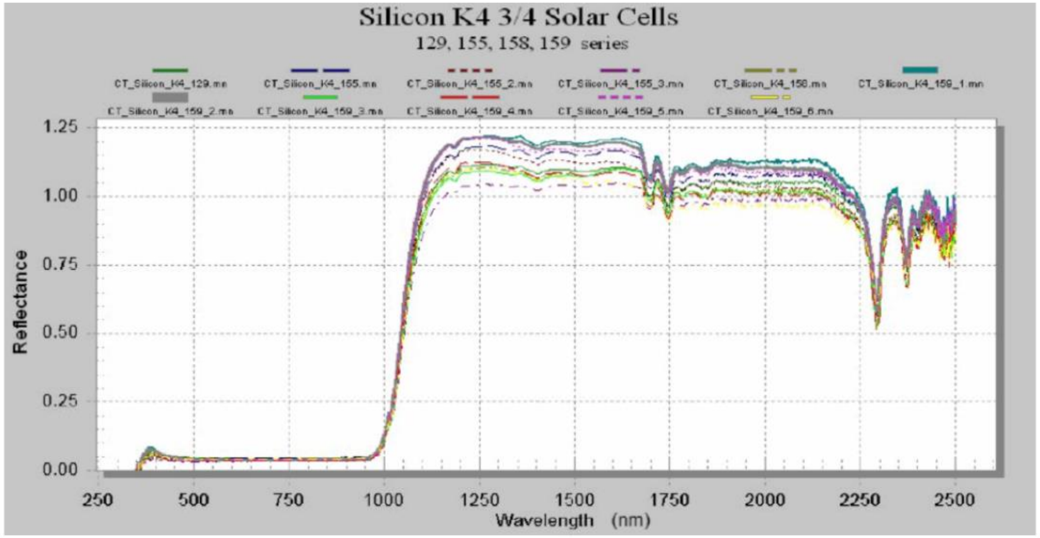
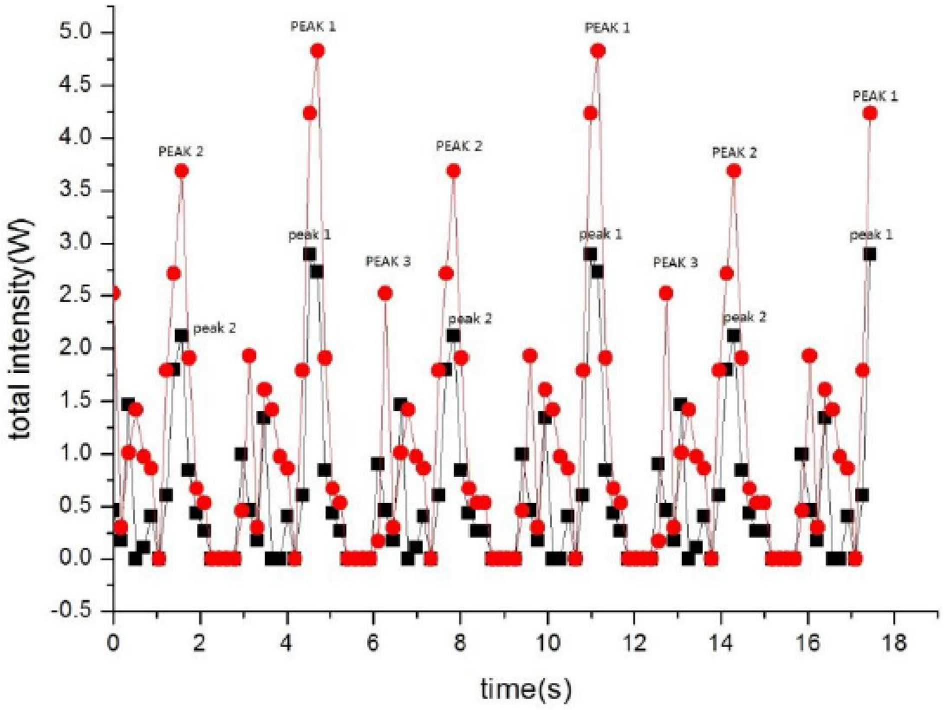


Figure taken from J Reyes & D Cone, Adv Maui Optical and Space Surveillance Tech Conf (AMOS) 2018

Time Signature example



Li Xue, Ming Li, Liangliang Wang, Qing Mao, "Spin velocity measurement for space debris from periodic signatures with active and passive illumination," Proc. SPIE 9270, Optoelectronic Devices and Integration V, 92701D (24 October 2014); doi: 10.1117/12.2070406

Event: SPIE/COS Photonics Asia, 2014, Beijing, China

Passive illumination Al_2O_3 (black) and TiO_2 (red) passive illumination response

Conclusion

- Investigating whether MKID's unique capability could provide a new means of identifying and potentially tracking space debris via a piece of debris's spectral time signature.

- Ph.D project just started Oct 2019 (Saeed Vahedikamal)

Acknowledgement: We are very gratefully to Prof B Mazin, UCSB for permission to use his MKID figures in this presentation.