MKIDs: Next Generation Direct Exoplanet Imagers

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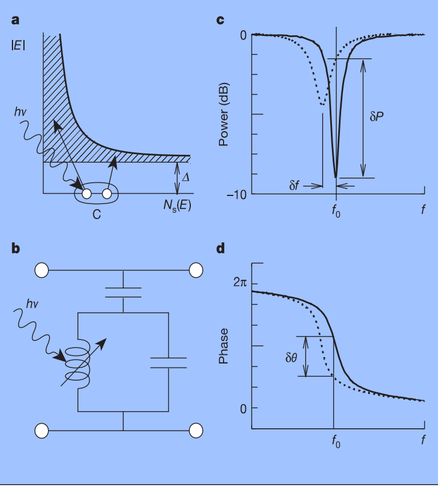
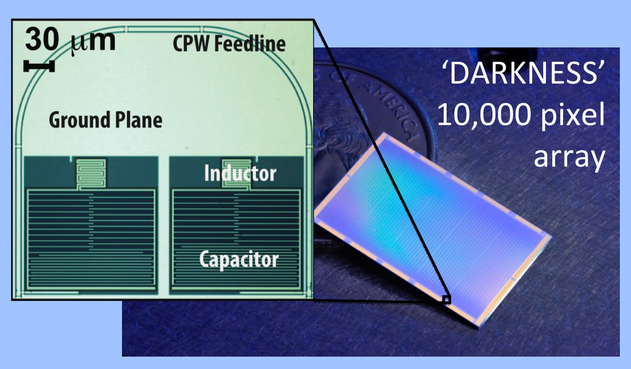
Taking direct images is crucial for our ability to characterise exoplanets. MKIDs, a photon counting energy resolving detector being developed at Oxford, have the potential to change the way exoplanets are imaged and revolutionise exoplanet detection.

MICROWAVE KINETIC INDUCTANCE DETECTORS

Microwave Kinetic Inductance Detectors (MKIDs) are a new cryogenic detector technology





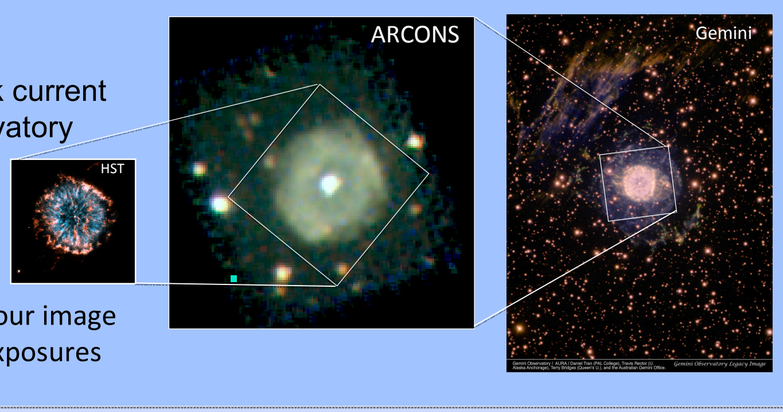
a) Photon is absorbed into superconducting inductor -> breaks Cooper pairs
b) Inductance shifts -> frequency shift in resonator circuit
c) and d) amplitude and phase shift of readout tone -> energy of incident photon

B. Mazin, Microwave Kinetic Inductance Detectors, Ph.D. thesis, California Institute of Technology (2004)

ARCONS: WORLD'S 1ST OPTICAL MKID CAMERA

- 2024 pixels
- λ = 400-1100nm
- R= E/ΔE = 8 at 450nm
- Zero read noise and dark current
- Palomar and Lick Observatory

B. Mazin, PASP, 123, 933, 2013



- NGC 6751 false colour image
- Mosaic of 37 30s exposures

BENEFITS FOR ASTRONOMY

1. **Photon counting**
2. **No read noise**
3. **No dark current**
4. **Energy resolving** (10%)
5. **Precise time resolution** (1μs)
6. **Broad simultaneous bandwidth** (300-2500nm)
7. **Simple design**
8. **Large array** (frequency domain multiplexing)

	Sensitivity	Noise	Time resolution	Energy resolution	Array size	Cost/unit
MKIDs	*Fair*	*Excellent*	*μsec*	*Fair*	*Fair*	*Moderate*

The technology is still in its infancy

Sensitivity & Array size → Excellent

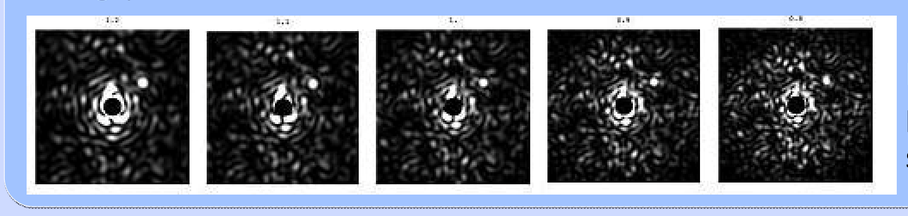
SPECKLE NOISE

- Beyond the contrast problem AO systems are limited by speckle noise
- Speckles arising from optical path differences in the beam causing interference
- Can last minutes and overwhelm a faint exoplanet
- Speckles fixed to the telescope vary as a function of time and colour

Angular Differential Imaging: Rotate telescope about line of site and subtract the rotated image from the nonrotated image

Spectral Differential Imaging: Take simultaneous images in adjacent wavelengths and combine them to suppress the speckles

- Time resolution of MKIDs ~ μs -> much less than turbulence lifetime
- No extra readout noise from short exposures
- Science plane can act as the wave front sensor rather than using separate optics -> increases throughput
- MKIDs eliminate the need for the optics of an Integral Field Spectrometer -> increasing throughput



P1640 datacube planetary system simulation

DARK SPECKLE IMAGING

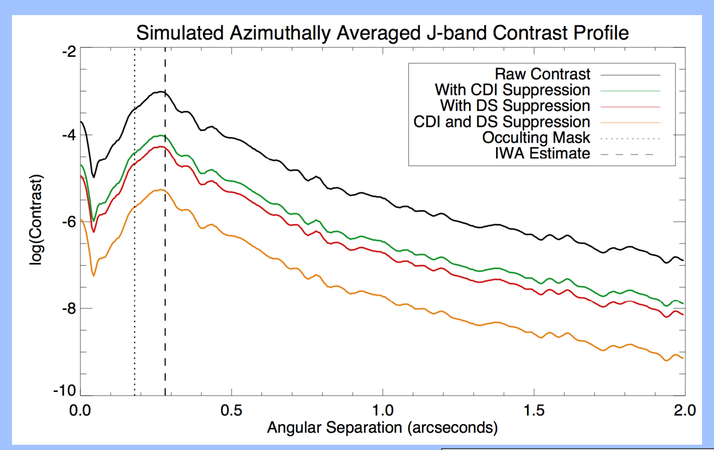
A. Labeyrie, 1995A&A...298..544L

- Exoplanet detection technique not previously possible before MKIDs
- Can see companions fainter than speckles
- Map the dark speckles (where speckle wavefront destructively interferes) -> stack many images -> companion planets appear as bright spots in a dark image
- Previously required large number of pixels to get SNR at such small time scales
- IR observations offer best contrast but IR arrays inherently have high noise at small time scales

- MKIDs have temporal resolution faster than speckle lifetime
- Spatial resolution smaller than speckle size
- No read noise (even on short time scales)
- No dark current so dark speckles perfectly dark

PROJECT 1640 MKID IMAGING SPECTROGRAPH

P1640 comprises of an extreme adaptive optics system, a modified Lyot coronagraph, a wavefront sensor calibration unit and currently an integral field spectrograph



DARKNESS – The DARK-speckle Near-infrared Energy-resolving Superconducting Spectrophotometer, will replace the P1640 IFS

- 10,000 pixels
- λ = 800-1400nm
- R= E/ΔE = 20 at 1μm
- Spring 2016

http://web.physics.ucsb.edu/~bmazin/Posters/SPIE2014.jpg

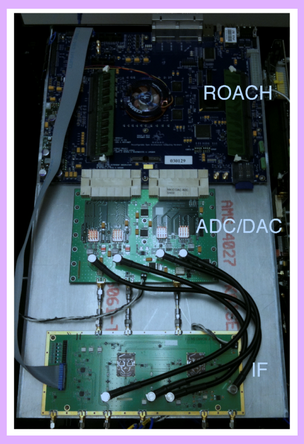
MKIDS AT OXFORD UNIVERSITY

Oxford University are very active in MKID research and development. The project is fully funded by the STFC and additional support has recently been acquired from the Oxford University.

Oxford are providing a leading role in the UK MKID movement. We have close collaborations with Stafford Withington at the Cavendish laboratory, Cambridge and Ian Hepburn at the Mullard Space Science Laboratory.

Work is currently being done to set up the FPGA based ROACH readout for a medium spectral resolution, optical and near-IR spectrograph.

K. O'Brien et al. KIDSpec: an MKID based medium resolution integral field spectrograph. SPIE 9147



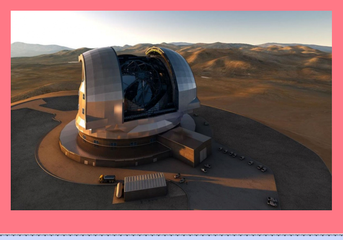
Sean McHugh et al. 2012RScI...83d4702M

CURRENT & FUTURE POTENTIAL EXOPLANET MKIDS

SPHERE: integral field spectrograph on the VLT

PCS: integral field spectrograph on the E-ELT - potential capability to image and characterise M_{Earth} exoplanets

Eliminating the need for IFS optics and hugely reduced readout noise, MKIDs could dramatically improve the sensitivity of these ambitious projects



COULD MKIDS BE A GAME CHANGER FOR ELT-PCS?