# SPACEKIDS: Kinetic Inductance Detector Arrays for Space Applications

M. Griffin[1], J. Baselmans[2], A. Baryshev[3,4], S. Doyle[1], M. Grim[2], P. Hargrave[1], T. Klapwijk[5], J. Martin–Pintado[6], A. Monfardini[7], A. Neto[5], H. Steenbeck[8], I. Walker[1], K. Wood[9], A. D'Addabbo[7], P. Barry[1], A. Bideaud[1], B. Blázquez[5], J. Bueno[2], M. Calvo[7], J-L Costa-Kramer[6], L. Ferrari[3], A. Gómez-Gutiérrez[6], J. Goupy[5], N. Llombart[5], S. Yates[3]

[1]School of Physics and Astronomy, Cardiff University, UK
[2]SRON, National Institute for Space Research, Utrecht, The Netherlands
[3]SRON, National Institute for Space Research, Groningen, The Netherlands
[4] Kapteyn Astronomical Institute, University of Groningen, The Netherlands
[5]Delft University of Technology, Delft, The Netherlands
[6]Centro de Astrobiología (CSIC/INTA), Madrid, Spain
[7]Institut Néel, CNRS & Université Joseph Fourier (UJF), Grenoble, France
[8]Aim Valley B.V., Hilversum, The Netherlands
[8]QMC Instruments Ltd., School of Physics and Astronomy, Cardiff University, UK

***Abstract* — Kinetic Inductance Detectors (KIDs) offer excellent sensitivity in the THz region combined with ease of operation. The SPACEKIDS project is working on developments needed to enable this technology for space. It includes development of antenna-coupled and lumped-element KIDS, and of the necessary readout electronics. KID arrays have been developed for both low-background (astrophysical) and high-background (Earth-observing) applications. Two laboratory demonstrator systems are now being used to evaluate kilo-pixel array characteristics and performance in an environment representative of both astronomy (low background) and Earth observing (high-background) applications.**

## I. INTRODUCTION

Superconducting detectors operating at sub-kelvin temperatures are currently the most sensitive detectors of THz radiation. Instruments using transition edge superconducting (TES) sensors and kinetic inductance detectors (KIDs) are already in use in ground-based astronomical instruments, but have yet to be flown in space. SPACEKIDS is a European Union FP-7 project with the objectives of developing advanced KID arrays and demonstrating their suitability for space applications in both astronomy and Earth observing.

KID detectors [1, 2] are based on superconducting resonant circuits. Absorbed electromagnetic radiation breaks Cooper pairs in the superconductor, changing the quasiparticle density and hence the kinetic inductance, so modifying the resonant frequency. Arrays can be fabricated with high Q-factors and resonant frequencies in the GHz region, meaning that thousands of pixels can be read out through a common coaxial cable and a single low noise amplifier. KIDs also have a high dynamic range and are easy to fabricate, consisting of only a few patterned metal layers. This makes them robust, reliable and easy to manufacture as large-format arrays.

## II. SPACEKIDS OBJECTIVES

SPACEKIDS includes the following activities:
(i) review and analysis of the scientific requirements for future astrophysics and Earth observing missions, and derive key specifications for different applications;
(ii) development and evaluation of suitable pixel and array designs using both antenna-coupled and lumped-element KID (LEKID) architectures;
(iii) development and manufacture of 2-GHz bandwidth readout electronics suitable for use with kilo-pixel KID arrays;
(iv) fabrication and comprehensive testing, in representative laboratory test-beds, of prototype kilo-pixel arrays operating in both low and high photon background, in order to demonstrate some of the key performance parameters relevant to future space missions.

## III. CURRENT STATUS AND PLANS

SPACEKIDS is now in the third and final year of its three-year programme. An in-depth study of future mission requirements has been carried out to define detailed performance specifications for the SPACEKIDS arrays and the demonstrator systems, including electromagnetic radiation bandwidth, background power levels, sensitivity (NEP), $1/f$ noise, speed of response, crosstalk rejection, dynamic range and linearity. Table 1 summarises the ultimate detector requirements for possible future astrophysics missions: a double-Fourier far infrared interferometer such as FIRI [3], a camera and a grating spectrometer for use on a space telescope with a telescope temperature of 5 K such as SPICA or CALISTO [4, 5] or 25 K, such as Millimetron [6], and a mission to study the polarization of the Cosmic Microwave Background, such as COrE+ [7].

| | Double Fourier Interfero-meter | Camera<br>5 K telescope (25 K telescope) | Grating Spectrometer<br>5 K telescope (25 K telescope) | CMB Polaristation Experiment |
|---|---|---|---|---|
| λ (μm) | 30 - 400 | 30 – 3000 | 30 - 400 | 400 – 3000 |
| λ/Δλ | 2 | 3 | 1000 | 3 |
| NEP (W $Hz^{-1/2}$ x $10^{-19}$) | 1.1 – 4.6 | 1.2 – 3.8<br>(3.9 – 52) | 0.05–0.16<br>(0.16 – 2.2) | 19-51 |
| Time constant (ms) | 0.2 | 30 | 100 | 5 |
| No. of pixels | $20^2$ | $300^2$ | $300^2$ | $300^2$ |

Table 1: Detector requirements for future low background astrophysics missions

The SPACEKIDS demonstrator systems are not intended to achieve quantitative compliance with all of the performance requirements of these possible future missions, but to demonstrate significant advances with respect to current state of the art and the potential for KIDs to be considered as the technology of choice for such future missions with appropriate future technology development. The requirements for the low-background demonstrator are summarised in Table. 2.

| **Parameter** | **Requirement (goal)** |
|---|---|
| Wavelength λ (μm) | 150 |
| λ/Δλ | 3 |
| NEP (W Hz$^{-1/2}$ x $10^{-19}$) | 5 (1) |
| Time constant (ms) | 1 (5) |
| Detector absorption Efficiency | 0.5 (0.7) |
| Dynamic range | 500 (1000) |
| Array yield | 60% (70%) |

| **Parameter** | **Requirement (goal)** |
|---|---|
| Electrical crosstalk (dB) | 20 (30) |
| No. of pixels | 500 (1000) |
| Pixel size (mm) | 1 (5) |
| Cosmic ray dead-time | < 30% < 10% |
| Linearity | 5% (1%) |
| 1/f knee Frequency (Hz) | 0.5 (0.02) |
| Max source power (fW) | 5 (100) |

Table 2: Low-background demonstrator parameters

For the Earth-observing (high background application) we have adopted a new instrument concept, based on the science requirements for the approved Ice Cloud Imager (ICI) instrument on the MetOp-SG satellite [8], to characterise the detector requirements. The corresponding requirements for the high-background demonstrator are listed in Table 3.

| **Parameter** | **Requirement (goal)** |
|---|---|
| Frequency ν (GHz) | 350 |
| Resolution (ν/Δν) | 100 (1000) |
| NEP (W Hz$^{-1/2}$ x $10^{-17}$) | 3.8 (1.2) |
| Time constant (ms) | 15 (7) |
| Detector absorption Efficiency | 0.5 (0.7) |
| Dynamic range | 2 (10) |
| Array yield | 60% (70%) |

| **Parameter** | **Requirement (goal)** |
|---|---|
| Electrical crosstalk (dB) | 20 (30) |
| No. of pixels | 500 (1000) |
| Pixel size (mm) | 1 (2) |
| Cosmic ray dead-time | < 30% < 10% |
| Linearity | 5% (1%) |
| 1/f knee Frequency (Hz) | 0.1 (0.05) |
| Background power (pW) | 1.8 (0.2) |

Table 3: High-background demonstrator parameters

There has been a wide range of modelling and experimental activity, with considerable progress made in all respects. Both antenna-coupled and lumped-element KID array designs have been developed which can meet the performance requirements. Modelling of KID-KID cross-coupling has quantified the degree to which it depends on inter-pixel distance and on the differences in resonant frequency, leading to the development and verification of an array design strategy to minimise the effects, and showing that KID arrays can be made with negligible cross coupling. KIDs based on aluminium films have been shown to meet the sensitivity requirements, with photon noise limited performance down to background power levels of 0.1 fW. For antenna-coupled KIDS, a novel dual-band leaky-wave lens-coupled antenna has been developed [9], as has a fabrication and integration scheme for silicon lenslet arrays.

A method of lowering the susceptibility of the detectors to glitches caused by cosmic ray impacts has been modelled and experimentally proven.

The necessary electronics to read out a kilo-pixel KID array with 2 GHz total bandwidth has been developed and tested, and the cryogenic test-beds for array evaluation and demonstration have been built, one located at SRON, Utrecht for low background tests and one at Cardiff University for high background testing. Following fabrication of the final demonstration arrays, full testing of both high- and low-background arrays is about to start.

In parallel with the experimental demonstrations, the SPACEKIDS team will carry out conceptual studies of KID based space instruments for astrophysics and for Earth observation. On completion of the project, results will be presented at an open community workshop in early 2016.

Acknowledgements: SPACEKIDS is a collaborative project funded via grant 313320 provided by the European Commission under Theme SPA.2012.2.2-01 of the Framework Programme 7.

## REFERENCES

[1] Day, P. K., et al., A broadband superconducting detector suitable for use in large arrays", *Nature*, 425, 2003

[2] Doyle, S., et al., "Lumped Element Kinetic Inductance Detectors", *Journal of Low Temperature Physics*, 151, 530, 2008

[3] Helmich, F., and Ivison, R., "FIRI—A far-infrared interferometer", *Experimental Astronomy*, 23, 245, 2009

[4] Roelfsema, P., et al., "The SAFARI imaging spectrometer for the SPICA space observatory", *Proc. SPIE*, 8442, 84420R, 2012

[5] Goldsmith, P., et al. "CALISTO: A Cryogenic Far-Infrared/Submillimeter Observatory", *Proc. SPIE*, 6687, 66870P, 2007

[6] Smirnov, A. V., et al., "Space mission Millimetron for terahertz astronomy", *Proc. SPIE*, 8442, 84424C, 2012

[7] Delabrouille, J., "COrE+ The Cosmic Origins Explorer A proposal for ESA's M4 space mission". *University of Minnesota Digital Conservancy*, http://hdl.handle.net/11299/169642.

[8] Kangas, V., et al. "Metop Second Generation microwave sounding and microwave imaging missions", *Proc. EUMETSAT Meteorological Satellite Conference*, Sopot, Poland, Sept. 3-7, 2012

[9] Neto, A., at al., "THz Leaky Lens Antenna integrated with Kinetic Inductance Detectors, *Proc. Pulsed Electromagnetic Fields: Their Potentialities, Computation and Evaluatio*n, 121, 2013