S-Cam 2. Performance and initial astronomical results

N. Rando¹, J. Verveer¹, P. Verhoeve¹, A. Peacock¹, S. Andersson¹, A. Reynolds¹, F. Favata¹,
M. Perryman¹, D. Goldie²

¹*Astrophysics Division, Space Science Department, ESA/ESTEC, P.O. Box 299,
2200 AG Noordwijk, The Netherlands*

²*Oxford Instruments Scientific Research Division, Newton House, Cambridge Business Park,
Cowley Road, Cambridge CB4 4WZ, United Kingdom*

ESLAB 2000/018/SA

To be published in the Proceedings of SPIE, Vol. 4008

S-Cam 2. Performance and initial astronomical results.

N.Rando*, J.Verveer, P.Verhoeve, A.Peacock, S.Andersson, A.Reynolds, F.Favata, M.A.C.Perryman,
and D.J. Goldie⁺

Astrophysics Division, Space Science Department of the European Space Agency,
PO Box 299, NL-2200 AG, Noordwijk, The Netherlands.

⁺Oxford Instruments Scientific Research Division,
Newton House, Cambridge Business Park, Cowley Road, Cambridge CB4 4WZ, U.K.

ABSTRACT

S-Cam is a cryogenic camera for ground based astronomy designed around a 6x6 array of Ta-Al Superconducting Tunnel Junctions (STJs). The camera has been conceived as a technology demonstrator, aiming to prove the potential of this new generation of single photon counting detectors at a ground-based telescope as a possible precursor to space based applications. Following a first test campaign at the *William Herschel Telescope* in La Palma (Canary Islands, Spain), an improved version of the camera (*S-Cam 2*) has been developed and tested. In this paper we provide an overview of the latest camera performance, a description of the up-dated *S-Cam 2* system and a summary of the main test results. An example of the novel astronomical data obtained during the second test campaign conducted in December 1999 are also shortly described.

Keywords: electro-optical instrumentation, ground-based astronomy, photon-counting detectors, solid state detectors, focal plane array detectors, superconducting tunnel junctions, cryogenic equipment.

1. INTRODUCTION.

High quality Ta-Al Superconducting Tunnel Junctions (STJ) have now started to be used as photon counting imaging spectro-photometer over a broad energy range, from the Near Infrared to the UV and soft X-ray. Such detectors have demonstrated high responsivities (of order 10^4 e-/eV), high detection efficiency (about 70% at visible wavelengths), adequate wavelength resolving power ($\lambda/\Delta\lambda$ of order 20 at $\lambda = 300$ nm) and fast response time (of order 10 μ s). The combination of these characteristics makes medium format arrays of STJs an important tool for a new generation of optical astronomy instruments^{1,2}.

Following the photo-absorption process occurring in a superconductor, the energy of the photon E is transferred into a large number of charge carriers (quasiparticles), well in excess of any thermal equilibrium population. The number of charge carriers produced in the photo-absorption process is $N_0 = E/\epsilon$, where ϵ is the mean energy required to create a quasiparticle in the superconductor by breaking Cooper's pairs. In Ta, ϵ is estimated to be of order 1.2 meV². The excess charge is detected as a current pulse, driven by a dc voltage bias applied across the tunnel barrier, between the two electrodes forming the STJ. The responsivity of the detector is enhanced by multiple tunnelling, with each quasiparticle tunnelling on average $\langle n \rangle$ times before recombining, and a total amount of detected charge equal to $N = \langle n \rangle \cdot N_0$, thus leading to a detector responsivity $R = \langle n \rangle / \epsilon$ (where R is expressed in units of e-/eV). The intrinsic energy resolution of such a STJ detector (ΔE_I), is limited by fluctuations in the charge originally produced in the superconducting absorber (related to the Fano factor, F , with $F \cong 0.22$ in Nb and Ta) and by fluctuations in the average number of tunnels $\langle n \rangle$. In the case of a symmetrical junction, the intrinsic detector resolution (Full Width at Half-Maximum, FWHM) can be written as³:

$$\Delta E_d (eV) = 2.355 \cdot \sqrt{\epsilon \cdot E \cdot (1 + F + 1/\langle n \rangle)} \quad (1).$$

* Correspondence: E-mail: nrando@estec.esa.nl; WWW: <http://astro.estec.esa.nl>

For a Ta based detector, with $\langle n \rangle \rightarrow \infty$, the limiting energy resolution corresponds to about 0.19 eV at 4.133 eV ($\lambda=300$ nm), and an intrinsic resolving power $E / \Delta E = \lambda / \Delta \lambda \cong 22^4$. The measured energy resolution is however degraded by spatial non-uniformities in the detector responsivity, by the noise of the Front-End electronics and by statistical fluctuations associated with any background radiation (in this specific case essentially IR radiation originating from any bodies close or within the FOV of the detector). The total energy resolution, neglecting the spatial non-uniformities (relevant at x-ray energy, but small at visible wavelengths), can then be written as $\Delta E_{tot} (eV) \cong 2.355 \cdot (\sigma_{Ed}^2 + \sigma_{En}^2 + \sigma_{IR}^2)^{1/2}$. In this equation, σ_{En} represents the detector electrical noise in eV (where $\sigma_{En} = \sigma_n / R$, with σ_n representing the Equivalent Noise Charge in e-) and σ_{IR} describes the energy degradations induced by the presence of the background radiation. It can be shown that for a typical STJ, σ_{IR} can be described as follows⁵:

$$\sigma_{IR} (eV) \cong \sigma_{AC} (eV) = \sqrt{\langle E_{IR}^2 \rangle \cdot \Gamma_{IR} \cdot \tau} \quad (2),$$

where $\langle E_{IR}^2 \rangle$ represents the mean squared energy of the background photon energy distribution. It is important to notice that typically $\sigma_{IR} \geq \sigma_{En}$ and that this energy degradation mechanism does not depend on the detector responsivity, but only on the background radiation flux Γ_{IR} , and the signal integration time τ . In order to avoid background limited performance it is necessary to minimise any stray IR radiation by means of an adequate filters. Figure 1 shows the resolving power ($E / \Delta E = \lambda / \Delta \lambda$, typical pixel) as a function of wavelength for *S-Cam 1*⁶, *S-Cam 2* and as predicted by eq. 1 (intrinsic detector resolving power).

Figure 1. The resolving power of a typical pixel of an *S-Cam* array. The dashed line corresponds to eq.1, with $R = 1.0 \cdot 10^4$ e-/eV, $\langle n \rangle = 10$, $\sigma_{En} \cong \sigma_{IR} = 0$ eV (intrinsic detector resolving power). The solid line corresponds to the resolving power measured with *S-Cam 1*. The dotted line corresponds to the improved *S-Cam 2* performance.

The experimental results⁴ obtained with Ta-Al STJs at $T=0.3-0.4$ K have shown responsivities of order 10^4 e-/eV, single photon counting performance at wavelengths longer than $2.0 \mu m$ and excellent wavelength response linearity. Good fabrication yield and device reproducibility have allowed the successful manufacturing of a series of array demonstrators

(6x6 pixels) used in the *S-Cam 1* and *S-Cam 2* programs. Present development work is addressing the fabrication of larger format arrays (12x8 and 32x32). These developments, in conjunction with the short response times and high detection efficiency, make arrays based on STJ's attractive detectors for optical astronomical applications requiring simultaneous imaging, time tagging and energy resolution capability. Applications in science areas other than UV-optical astronomy can also be envisaged.

2. STJ DETECTOR ARRAY.

Improved Ta based, 6x6 element arrays with both 25 and 40 μm pixels have been recently developed, tested and integrated into the *S-Cam 2* cryo-magnetic system. The final *S-Cam 2* array is based on 36 diamond-shaped, 25 μm devices (figure 2), with a separation between adjacent pixels of 4 μm . The detectors are fabricated from an original Ta-Al-AlOx-Al-Ta multilayer, deposited by sputtering onto a highly polished, 520 μm thick sapphire substrate. The deposition of the superconducting films is performed without breaking vacuum: first the 100 nm thick, epitaxial Ta base electrode is deposited (Residual Resistance Ratio ≈ 45), followed by 30 nm of Al. After the barrier oxidation process, further 30 nm of Al are deposited, together with the top film of 100 nm thick Ta. A 350 nm thick SiOx passivation layer is deposited onto the multilayer to minimise oxidation and to isolate the counter-electrode wires.

Figure 2. Optical microscope photograph of a *S-Cam*, 6x6 Ta array (40 μm pixels). The wiring connecting the base and counter electrodes to the external pads are clearly visible, as well as the path of the return lines.

The individual STJs have a barrier resistivity of about $2.4 \cdot 10^{-6} \Omega \cdot \text{cm}^2$, with leakage limited subgap current densities of about $0.03 \text{ pA}/\mu\text{m}^2$ (measured at a bias voltage of 0.1 mV and at $T=0.30 \text{ K}$). The I-V characteristics are dominated by the leakage current up to a temperature of about 450 mK. The device energy gap, measured from the I-V characteristics, is 0.52 meV. Due to the thick Al layer, the *S-Cam 2* arrays have shown increased responsivity (from $6 \cdot 10^3$ to $15 \cdot 10^4 \text{ e-/eV}$). This significant increase in responsivity, in combination with an improved IR rejection, has allowed us to enhance the *S-Cam 2* signal-to-noise (S/N) performance (c.f. fig.1). The array and single pixel geometry has been carefully optimised to ensure optimal suppression of the dc Josephson current I_j for all pixels at the same magnetic field intensity: this particular aspect represents a crucial issue in successfully operating an array of superconducting tunnel junctions. The array geometry adopted for the *S-Cam* instrument has allowed us to reduce simultaneously I_j below 20 nA for all the 36 pixels at a typical field intensity of order 150 G. The electrical connections to the counter-electrode of the single device are performed by means of Nb wires deposited onto the SiOx passivation layer and connecting each pixel through small vias opened in the isolation layer. The fact that the counter-electrode wires pass over the pixels top film does not reduce the effective photo-efficiency of the arrays, since the detection of visible photons takes place in the base electrode of the device, through the sapphire

substrate. The active area of this 6x6 pixel detector, with 4 μm gaps, correspond to 74.3 % of the total array area. Note the back-illumination approach also presents the advantage of a higher detection efficiency (with respect to front-illumination) and additional IR rejection capability due to the absorption taking place in the substrate at wavelengths longer than 6 μm . Preliminary measurements⁷ have confirmed the theoretical expectations for the detector detection efficiency in back-illumination mode, with an efficiency in excess of 60 % at $\lambda = 230 \text{ nm}$. The base electrodes of the pixels within each single row of the array are connected via small Nb bridges (see figure 3); the use of Nb is crucial in minimising the diffusion of quasiparticles from one pixel to the adjacent ones, thereby avoiding any intrinsic cross-talk mechanism in the detector.

Figure 3. Optical microscope photograph of an *S-Cam*, array (40 μm pixels). The base and counter electrodes are visible, as well as the Nb bridges used to eliminate quasiparticle diffusion between adjacent pixels. All top contacts are in Nb.

Specific tests have been conducted by illuminating the array with 5.9 and 6.4 *keV* photons, thereby generating an original amount of charge more than 3000 times larger than the one involved with the detection of visible photons. Even in presence of such a high quasiparticle density, dedicated time coincident measurements have shown that quasiparticles diffusion from one pixel to the neighbours is negligible.

Figure 4. Charge spectrum obtained by pixel (4.4) illuminating the detector array with a pulsed led (red, 630 nm) when integrated into the *S-Cam 2* cryostat and undergoing system tests. The peak corresponding to 3 photon events falls partly above the PHA full scale.

Prior to its integration into the *S-Cam 2* system, extensive tests have been conducted in a ^3He cryostat, between 0.30 and 0.50 K, including visible, UV and x-ray stimuli. In this configuration, the detector is clamped to a cold finger, while a superconducting magnet provides a field parallel to the plane of the tunnel barrier, necessary to suppress the Josephson current and bias the detector. UV and visible light illumination takes place via a UV-grade silica fibre, which transmits the light emitted by a xenon lamp, through a grating mono-chromator.

The *S-Cam 2* array is read-out by means of 36 Charge Sensitive Preamplifiers (one for each pixel) and a related shaping stage, all at room temperature. The amplitude and the risetime of the detected pulse correspond to the total collected charge and to the decay time of the signal respectively. The noise performance is measured by the FWHM of the peak distribution generated by an electronic pulser. Figure 4 shows the charge spectrum obtained from pixel (4.4) when the detector array is illuminated by a pulsed red LED. The LED is activated for about $1\ \mu\text{s}$, while the repetition rate is typically 1 kHz. The integrated system test conducted prior to shipment to the WHT confirmed the good reproducibility of the electrical characteristics of the array elements and the possibility to operate all pixels at the same bias voltage (typically around $200\ \mu\text{V}$) and with uniform responsivity ($R \cong 15 \cdot 10^4\ \text{e-/eV}$). Typical responsivity variations (pixel to pixel) are below the 5% level. The devices show a characteristic pulse decay time of about $8\ \mu\text{s}$. Figure 5 shows in the form of a 3d histogram the correlation existing between the subgap current of each pixel at the bias voltage and the corresponding noise (electrical and IR background induced) performance. The noise level is expressed in eV, as the FWHM of the test pulser.

Figure 5. 3D histograms of the subgap current at the bias voltage and of the corresponding test-pulse energy resolution for all elements of the array. Pixels (5.2), (5.3) and (5.4) show larger subgap currents and worse energy resolution.

As it can be clearly seen, pixels (5.2), (5.3) and (5.4) show higher subgap currents and correspondingly larger noise levels, from an average just below 0.3 eV to a maximum of about 0.6 eV for pixel (5.4). The cause of this non-uniformity is not fully understood, but it could be related to the IR background seen by the detectors rather than to any intrinsic array defect. Obviously, the larger FWHM corresponds to a lower S/N and thus worse resolving power.

Figure 6 shows the resolving power ($\lambda/\Delta\lambda$) at $\lambda = 325 \text{ nm}$, for all elements of the array. The solid line corresponds to the average resolving power ($\langle\lambda/\Delta\lambda\rangle=10.3$, with $\sigma=1.107$), the top and bottom dashed line respectively to $\langle\lambda/\Delta\lambda\rangle+\sigma$ and to $\langle\lambda/\Delta\lambda\rangle-\sigma$. The performance of the pixels (5.2), (5.3) and (5.4) (i.e. channels 8, 9 and 10) is degraded by the larger noise, consistently with what is shown in figure 4. Most of the pixels have a resolving power comprised between 9.2 and 11.4, i.e.

Figure 6. Resolving power ($\lambda/\Delta\lambda$) of all elements of the *S-Cam 2* detector array at $\lambda=325 \text{ nm}$. The lower resolution of pixels (5.2), (5.3) and (5.4) (corresponding to channel numbers 8, 9 and 10) is due to the larger subgap currents shown in figure 4.

within $\pm 1\sigma$ from the average value. The camera performance has also been verified as a function of the photon count-rate. Figure 7 shows the behaviour of the Full Width at Half Maximum as a function of count-rate, when the array was illuminated by monochromatic light, at 500 nm . Between 500 and 4000 count/sec the energy resolution shows only a modest worsening, with the FWHM increasing by 7% (from about 0.29 to 0.31 eV).

Figure 7. Energy resolution at 500 nm (FWHM) as a function of count rate measured with *S-Cam 2* from pixel (4.4). The weak dependence from count rate shows the absence of any relevant pile-up effect.

3. S-CAM 2: DESCRIPTION OF THE CRYOGENIC CAMERA.

The characteristics of the *S-Cam* camera have been already reported in previous papers⁶ and for the reader's convenience are summarised again in Table 1 below. The main changes in *S-Cam 2* concern the increased resolving power (now of order 8 at 500 nm), the higher maximum count-rate sustained by each of the electronics channels (now equal to 5 kHz), the simplified alignment procedure and a number of improvements in the Graphical User Interface software. The camera design is based on a bottom loading ⁴He cryostat hosting an adsorption ³He cooler^{8,9}. A dedicated optical collimator unit interfaces the camera focal plane to the Nasmyth focus of the Ground High Resolution Imaging Laboratory of the William Herschel Telescope, in La Palma.

A plate scale of 0.6 *arcsec/pixel* was selected to match the telescope point spread function (typically $\cong 1$ *arcsec*). The optical unit is based on a reflective section and on a lens objective. Two filter wheels are available with neutral density and narrow band filters. The Front-End electronics is based on 36 charge sensitive preamplifiers and related shaping stages working at room temperature: these allow to individually bias and read-out each STJ of the array. Optimised shaping stage filters allow to maximise the signal to noise ratio without penalising the count-rate capability of the electronics (now increased to 5 kHz /channel). Each channel has a peak detection unit and an analog to digital converter which allow us to perform pulse height analysis on each detected photon. Every event is then associated with a highly accurate time of arrival provided by a commercial Global Positioning System receiver. The electronics system is controlled via a dedicated data acquisition computer, which is then interfaced with a remote control PC. Such a control PC functions as Graphical User Interface and allows the remote control of the main instrument functions (from the telescope control room), including the array operating parameters. The data storage takes place on the same unit, which also provides some limited data analysis capability (data 'quick-look' functions).

Table 1. *S-Cam* characteristics.

Band-pass:	350 – 650 nm (at 10 % photon collection efficiency).
Provided data per detected event:	Wavelength, arrival time, pixel identification.
Resolving power ($\lambda/\Delta\lambda$ (fwhm)):	of order 10 at 300 nm.
Event time accuracy:	5 μ sec (absolute time reference via GPS).
Maximum count rate:	5 kHz / pixel.
Camera field of view:	4.0 x 4.0 <i>arcsec</i> ² (plate scale = 0.6 <i>arcsec/pixel</i>).
Instrument installation:	Nasmyth focus (f/11) – William Herschel Telescope.
Observation time:	In excess of 10 hour (cooler hold time).
Camera focus adjustment:	Via telescope secondary mirror and dedicated optical unit.
Camera guiding:	Telescope facility (auto-guider camera).
Filter wheel:	2 sets of 8 filters on 2 independent wheels.
On-line data analysis:	'Quick-view' SW installed on control PC.
Data storage format:	FITS format (via control PC).

As a consequence of the high detector responsivity and detection efficiency, the rejection of thermal infrared photons is crucial for the camera performance, directly influencing the resolving power of the instrument (see section 1 above). While the expected sky background flux at the Nasmyth focus does not represent a major problem (with an expected integral number of counts of order 50 counts per second, per pixel), the thermal radiation emitted by warm parts in the field of view of the array affects drastically the system performance. The energy degradation, described by eq.2, is due to pile-up effects produced by the high rate and small amplitude pulses from the thermal radiation, superimposed on the signal from the visible photons. In order to minimise such an energy degradation mechanism, adequate IR filters must be used. In this latest configuration, *S-Cam 2* adopts two KG2 glass filters of different thickness, cooled at a temperature of 12 and 2 K respectively. A third silica element is located in front of the focal plane array and maintained at 0.32 K. The optical entrance window of the cryostat is sapphire, with standard ARC's on one side and a multi-layer IR filter on the opposite side. Mainly

due to the presence of these filters, the overall camera throughput in the nominal band-pass is of order 25 %. Further development work is on-going in order to improve the efficiency of the IR filters.

4. ASTRONOMICAL RESULTS.

The first test campaign performed with *S-Cam 1* has taken place in Jan.-Feb. 1999, at the William Herschel Telescope, in La Palma (Canary Islands, Spain). Such a campaign has allowed to verify all the interfaces between the instrument and the telescope and to identify any required improvements, but it has also demonstrated the potential of this new generation of detectors with time and energy resolved data from the Crab pulsar^{10,11} (figure 8 below).

Fig. 8 Pulse profile for the Crab pulsar, produced by *S-Cam 1*, from the 6 Feb 1999 data (310-610 nm range, 50 min observation).

Following the improvements described in section 3, we have performed the first of a series of astronomical demonstration campaigns at the WHT in Dec. 1999, this time focusing on the astronomical exploitation of the camera rather than on engineering aspects. The campaign demonstrated stable operations from all the 36 elements of the array and a performance level fully equivalent to what was recorded in the laboratory during the integrated system tests. One of the first astronomical objects observed during this campaign is UZ For, one of a class of short-period binary systems known as polars or AM Her

stars. The two stars which constitute this binary are very different: a low-mass dwarf star cooler than our sun but which is still burning hydrogen in its core, and a much smaller stellar remnant known as a white dwarf. White dwarves, the evolutionary end-point of a sun-like star, typically contain about as much mass as our own sun, but squeezed into a volume about the size of the Earth. In the case of polars, they are also highly magnetised, with surface magnetic field strengths ranging from 10 to 70 MG. The two stars are so close that they may orbit around each other in only a few hours, with matter being drawn off the ordinary dwarf star onto the surface of the white dwarf, giving off X-rays in the process. The white dwarf rotates synchronously with the binary period and its strong magnetic field prevents the in-falling matter from forming an accretion disk. Such systems are ideal candidates for study with *S-Cam* since they display a rich variety of spectral and temporal variations in the optical, due to the emission, absorption and occultation effects of the various system components: the dwarf star, accretion stream, and hotspot. While this makes them interesting from an astrophysical point of view, the requirement to combine high time-resolution with medium resolution spectroscopy has made them difficult to study using traditional dispersion spectroscopy/CCD techniques. *S-Cam*'s combination of energy sensitivity and millisecond timing capability - plus its exceptional detection efficiency - make it highly suited to the study of these binaries. Figure 9 shows an *S-Cam* observation of the eclipse transition of this 127 minute binary UZ For in three energy bands (low, medium and upper). The energy bands were defined by dividing the full PHA range in three energy (i.e. wavelength) intervals. The low energy band extends from 1800 nm (corresponding to the PHA analog threshold amplitude) to 620 nm; the medium energy band extends from 620 nm to 525 nm and the high energy band from 525 nm to 215 nm. It should be noted that the *S-Cam* photon collection efficiency at wavelengths longer than 750 nm and shorter than 325 nm is below 1%, while it peaks at 525 nm, just above 25%. The data, provided by all the pixels of the array, have been rebinned into 3 second time intervals for the sake of clarity. The eclipse corresponds to the white dwarf passing behind the normal dwarf star, which itself contributes very little light. The extremely sharp eclipse transition demonstrates that most of the emission is coming from a very small region, probably the accretion hotspot on the surface of the white dwarf. Just after the onset of the eclipse, a ledge-like structure is seen in the light curve that persists for a few seconds before falling off less sharply; this is probably the contribution from the white dwarf's photosphere.

5. CONCLUSIONS.

The capability to provide simultaneously imaging, arrival time and spectro-photometric information make Superconducting Tunnel Junctions a good candidate for the next generation of detectors for optical astronomy. Ta-Al based devices have demonstrated single photon counting capability at wavelengths longer than $2\ \mu\text{m}$ and responsivity ranging from 10^4 to $10^5\ \text{e}^-/\text{eV}$ at an operating temperature of 0.3 - 0.5 K. On this basis, 6x6 Ta arrays with $25\times 25\ \mu\text{m}^2$ pixels have been fabricated and successfully operated in the Visible, UV and X-ray regime, showing uniform performance and demonstrating the possibility to perform multichannel operations. The detectors do not have any significant cross-talk between adjacent pixels, while the Josephson current of the pixels can be satisfactorily minimised at a common magnetic field intensity.

Following the first *S-Cam* technological demonstration and test campaign at the William Herschel Telescope (Jan.-Feb. 1999), *S-Cam 2* has demonstrated improved performance, with enhanced resolving power, larger count-rate and improved operations. The instrument has now demonstrated its capability of producing astronomically relevant data. The typical camera applications capitalise on the specific characteristics of Superconducting Tunnel Junction detectors, with particular emphasis on the time resolution and simultaneous spectro-photometric capabilities (e.g. study of time variable objects, such as pulsars and binary systems). Despite the presently limited FOV and the modest spectral resolution, *S-Cam 2* has provided valuable astronomical results during a series of observations conducted at the WHT in December 1999. A new series of observations is presently scheduled at the end of April 2000.

The camera design has continued to evolve in parallel with the detector array development, with particular regard to larger array formats and innovative read-out schemes, allowing a significant enlargement of the related FOV. While larger format arrays can be produced within the limits of the present fabrication technology, the current front-end approach may require significant changes in order to read-out in excess of 10×10 elements. Parallel development activities are ongoing in order to determine alternative read-out schemes^{12, 13}, thus opening the way to considerably larger format arrays. Additional development work is underway in order to improve further the wavelength resolving power by using more effective IR filters and/or by modifying their configuration inside the cryostat. In addition, the migration to lower energy-gap superconductors, with a commensurate increase in resolving power (c.f. equation 1), is now under study. Finally, a considerable effort is being invested in simplifying the instrument operations, by limiting the need for cryogenic liquids and by adopting innovative

cryogenic technologies. Such changes will allow the operation of future generations of this type of camera at remote observation sites as common user facilities.

Figure 9. Eclipse transition of the binary UZ For in three energy bands (low, medium and upper). The low energy band extends from 1800 nm (corresponding to the PHA analog threshold amplitude) to 620 nm; the medium energy band extends from 620 nm to 525 nm and the high energy band from 525 nm to 215 nm. The counts were provided by all the 36 elements of the array, without any filtering procedure.

6. REFERENCES.

1. A.Peacock, P.Verhoeve, N.Rando, A.van Dordrecht, B.G.Taylor, C.Erd, M.A.C.Perryman, R.Venn, J.Howlett, D.J.Goldie, J.Lumley and M.Wallis, *Nature*, 381, 135 (1996).

2. A.Peacock, P.Verhoeve, N.Rando, C.Erd, M.Bavdaz, B.G.Taylor, D.Perez, *Astron.Astrophys.* 127, 497 (1998).
3. D.J.Goldie, P.L.Brink, C.Patel, N.E.Booth and G.L.Salmon, *Appl.Phys.Lett.*, 64, 3169 (1994).
4. P.Verhoeve, N.Rando, A.Peacock, A.v.Dordrecht, A.Poelaert, D.Goldie, *IEEE Trans.Appl.Supercon.*, 7, 3359 (1997).
5. J.B.le Grand, C.A.Mears, S.E.Labov, P.Jakobsen, P.Verhoeve, M.Bavdaz and A.Peacock, 106-107, *Proceedings of Low Temperature Detectors 7, Munich (1997)*, ISBN 3-00-002266-X.
6. N.Rando, A.Peacock, S.Andersson, B.Collaudin, P.Gondoin, J.Verveer, P.Verhoeve, D.J.Goldie, R.Hart. *Proceedings of SPIE 1998*, vol.3445, 74-80.
7. P.Verhoeve, N.Rando, A.Peacock, A.van Dordrecht, M.Bavdaz, J.Verveer, D.J.Goldie, M.Richter and G.Ulm, 97-100, *Proceedings of Low Temperature Detectors 7, Munich (1997)*, ISBN 3-00-002266-X.
8. L.Duband, *Cryogenics*, 30, 263 (1990).
9. J.Verveer, N.Rando, B.Collaudin, S.Andersson, P.Gondoin, and A.Peacock, *Rev.Sci.Instrum.* 70, 4088 (1999).
10. M.A.C.Perryman, F.Favata, A.Peacock, N.Rando, and B.G. Taylor, *Astron.Astrophys.* 346, L30-L32 (1999).
11. N.Rando, S.Andersson, B.Collaudin, F.Favata, P.Gondoin, A.Peacock, M.Perryman, J.Verveer, P.Verhoeve and D.J.Goldie, to be published in the proceeding of *Low Temperature Detectors 8 – Aug. 1999 – Dalfsen (NL)*.
12. D.D.E.Martin, A.Peacock, P.Verhoeve, A.Poelaert, R.Venn, to be published in the proceeding of *Low Temperature Detectors 8 – Aug. 1999 – Dalfsen (NL)*.
13. P.Verhoeve, R.den Hartog, D.Martin, N.Rando, A.Peacock, G.Brammertz, D.J.Goldie, to be published in the proceedings of '*Astronomical Telescope Instrumentation 2000*', 27-31 March 2000, Munich (Germany). Volume 4008.

7. ACKNOWLEDGEMENTS.

The authors would like to acknowledge the key role played by Bent Christensen (Unigate Technologies, DK) and by John O'Leary in the development of the camera software, as well as the support received by Frans Moser on the data acquisition hardware. R.Hart and D.Glowacka (Oxford Instruments, UK) have provided invaluable support during the detector manufacturing. Finally, we acknowledge the excellent support from the WHT staff and in particular P.Moore and C.Benn (Isaac Newton Group, La Palma, Spain).