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The CP20++ photon-counting detector: current status and use in Dark-Speckles experiment for Exo-Planet detection

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Abstract. In this article we present the CP20++ photon counting system, its use in the Dark Speckles (Labeyrie, 1995) experiment for exo-planet detection and its planned improvements. After describing the whole system and its components, we will sum up its current performances in term of spatial resolution, quantum efficiency, spectral response, electronic noise and real-time data processing. We will briefly expose its use in the Dark-Speckles experiment and finally, the planned hardware & dedicated software developements and its use in optical long baseline interferometry at blue wavelengths.

1. Introduction

The CP20++ system is the result of specific needs especially in optical interferometry. With the recent progress of computer technologies at affordable prices, the perspective for a 'real-time' acquisition device system has emerged and has now became possible. The CP20++ system described in this article is a complete revision of a first generation CP20 system which was used for the Dark-Speckles experiments at the Observatoire de Haute Provence in November 1997. The storage capacities and general lack of power showed up the need for a better system. The future improvements of the detector also enlights its use for long baseline interferometry at blue wavelengths.

2. Detector's components

The CP20++ includes 3 sub-systems which are: the photon counting camera head, the photon centroiding electronics and the real-time data processing computer.

2.1. The CP20 camera

The CP20 camera (Percheron & Vakili, 1990) has a 384x288 spatial resolution on the final CCD detector. The front detecting photocathode (Figure 1) is a first generation S20 intensifier cooled at $-20°$C with equivalent pixel size of 50μm. A second generation S20-P20 proximity intensifier and a microchannel plate amplifies the signal up to about 3.10^4. The resulting image is then transported to the CCD detector by a fiber optics taper with a 20/14mm reduction ratio to fit the CCD format. This process allows single photo-event detection and a very low dark count less than 10 photons per 20ms exposure which corresponds to approximatively 5.10^{-3} $photon.s^{-1}pixel^{-1}$ for 50μm pixels at $-20°$C. The resulting photo-event image on the CCD detector has a typical spatial area of 9 pixels though depending on the position. The CCD delivers the image signal in the CCIR video standard (50 images/s).

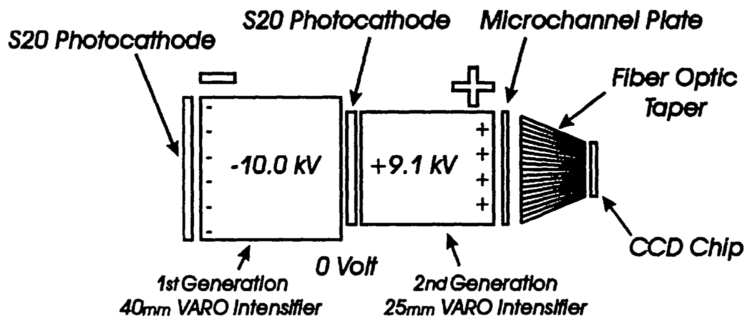

Figure 1. The CP20 camera

2.2. The centroiding device

The image signal is then transmitted to the photon centroiding device which computes the (x,y) coordinates of each photo-event. The video signal is digitized on 8bits and synchronized with the pixel clock. Each pair of coordinates is coded over 24bits and fed to a 24bits 1024k FIFO (First In First Out) memory. Due to hardware limitations and temporal and spatial hoto-events' coincidence, the linear photometric limit is reached for about 1.000 photons per 20ms short exposure. Known hardware artefacts such as double photons, remnent photons or centroiding hole (Berio & Vakili et al., 1998) can be corrected using post-acquisition image processing (see below).

2.3. Real-time processing computer

Hardware description An interesting feature of the CP20++ system is its ability to perform real-time data processing. The processing unit is a bi-processor PC clocked at 333MHz with 256MB (mega bytes) memory. To take advantage of the high RAM storage capacity, we use a dedicated DMA (Direct Memory Access) acquisition board which releaves the two processors for this time-consuming task. The stored (x,y) coordinates are then independently processed by the computer thanks to the DMA feature. The PC unit can also be used to have a quick look at intermediate pupil and/or image planes of the optics set-up thanks to a frame grabber board. Planned improvements of the system will include software control of analog data as well. Other features like high capacity mass storage devices (removable hard drive disks and CD-Rom writing) are part of the system.

Software description A specific and dedicated software application has been written in order to perform the real-time processing. We used a Visual C++

programing package which allows the creation of 'user-friendly' graphical interfaces. This could also allow the management of the large memory blocks required for the application. We have experimented the creation of up to 40MB data files in real observations but the only limitation should be the memory space. Multitasking was mandatory to be able to use the mutli-processor performances and also provides more flexibility for the user. This software controls the acquisition parameters such as real-time integration, real-time dark speckles computation & integration (see below), real-time auto-correlation & integration of short exposures. The result of all these processes are displayed with adjustable color table and allows a quick look on the data. More complex operations or multiple processes running at the same time have not been tested yet. Though, the power of bi-processing allows simultaneous acquisition & post-image processing. The processing speed is widely compatible with the hardware and tests have confirmed the system's performances up to 4.000 photons per short exposure.

3. Current performances of the CP20 detector

3.1. Quantum efficiency

Quantum efficiency has been measured (Hamma, 1993) at several walengths (Figure 2) and reaches its maximum in the Green/Yellow spectrum part. The tests includes hardware artefacts removal (double and remnant photons).

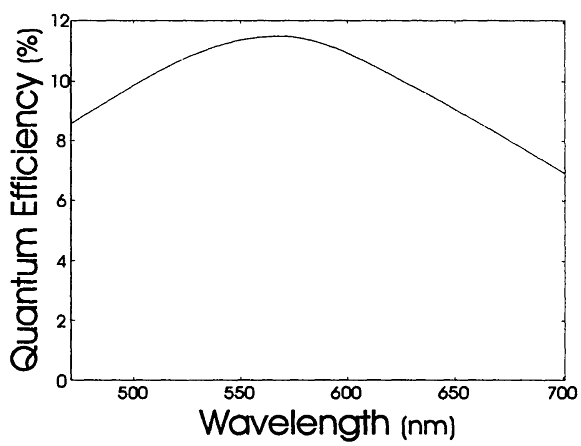

Figure 2. Quantum efficiency vs spectrum wavelengths

3.2. Global response

In order to know the camera's global response, a flat field acquisition has been performed. The figure below (Figure 3) shows the response integrated in the 'y' axis. It's a typical gaussian profile with a side extinction reaching 50%.

Figure 3. The CP20 camera's global spatial response

3.3. Real-time data processing

3.4. Known hardware artefacts

Double detection of a photon event This phenomena is responsible of the creation in an exposure of an artificial photon located at the same column as an existing photon and at the next line of the CCD matrix. A study (S. Hamma, 1993) has shown that the amount of doubled photons reaches 15% for a significant number of exposures. It is easy to locate such artefacts and clean the data file by removing the lower photon.

Remnent photons Two consecutive exposures can be affected by remnent photo events due to remanence of phosphors and creating a photo-event information at the same position. It is also easy to remove such photons since at low flux, the probability of two events at the same place become neglectable (though depending on the type of the observed object). There are typically between 5 to 10% of remaining photons depending on the flux.

Photon centroiding hole Due to the spatial extension of each photo-event on the CCD matrix we compute its photo-center in order to produce the (x,y) coordinates. Consequently, and due to the hardware algorithm used, it is impossible to separate multiple and spatially close photo-events. It produces a 'hole effect' all round the computed (x,y) coordinates within an approximate 3×3 pixels area (which is the average photo-events' extension). Consequently, and aside from the spatial coincidence of photo-events, the photon count in the image is biased but can be corrected using the spatial frequency informations (Berio & Vakili et al., 1998).

3.5. Current use in the Dark-Speckles experiment

An observing run has been held during October-November 1997 at the Observatoire de Haute provence in order to test the theorical validity of the Dark-Speckles technique for exo-planet detection which requires coronographic and adaptive optics (AO) sets. The AO was provided by the Office National d'Etudes et de Recherches Aérospatiale (O.N.E.R.A.). Due to low mass storage capacities, global performances of the previous acquisition unit (Amiga 2000 with DSP board) and misadjustments of the Lyot-type stellar coronograph (Boccaletti & Labeyrie), all the desired observations couldn't be done properly. The need for a reliable system with high datas storage devices then appeared necessary. The CP20++ perfomances have been successfully tested under intensive using conditions without any problems during coronographic qualifying tests at the O.N.E.R.A. using the BOA adaptive optics for the Dark-Speckles technique.

4. Future developments

The main improvement deals with the replacement of the CCD chip by a new 512×512 GEC. It will allow 150 frames/s fast read out and an improved photometric linearity in the visible. A DSP acquisition board will be added to perform software photon-centroiding and pre-image-processing tasks. Its use in long baseline interferometry, especially at the Grand Interféromètre à 2 Télescopes (GI2T) will be possible at blue wavelengths.

Acknowledgments. A. Labeyrie, A. Boccaletti, C. Moutou, P. Antonelli, D. Mourard.

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