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CPNG-Algol: photon-counting cameras for visible interferometry

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Abstract: We have developed a new generation of photon counting cameras for interferometric observations in visible wavelengths. Using image intensifiers with very high quantum efficiency, they are more efficient than previous generations and open new classes of objects to observation. Their modular design, with standard components, allows customization and easy maintenance and evolution. Photon localization, data acquisition and storage are achieved on a PC. Five cameras were built, with various specifications allowed by the modular design. Tests showed a good quantum efficiency in photon counting mode, reaching 36 % in blue to green wavelengths, and 28 % in red ones (with two different photocathodes).

1 Introduction

High angular resolution techniques of observation must compensate for, or at least have a faster readout than the atmospheric turbulence, else the interferometric structures will be blurred. In visible wavelengths the coherence time is low, typically 5 to 50 ms. This requires fast detectors, without readout noise. A photon counting camera consists in one or two image intensifiers coupled to a readout CCD camera; with a high optical gain (a few 10^6) and no readout noise it detects individual photons, its sensitivity being limited only by the photocathode quantum efficiency.

We developed a new generation of intensified CCD photon counting cameras for high angular resolution instruments: SPID speckle interferometer, GI2T interferometer and the VEGA proposal for CHARA: to use the GI2T spectrograph and detectors on CHARA interferometer to combine up to 4 telescopes in visible wavelengths. It is designed to replace CP40 photon counting systems (Blazit, 1986, Foy, 1988), intensified CCD cameras with 40 mm diameter photocathode and 4-CCD readout. Its sensitivity was too low for many interesting objects. CPNG-Algol cameras are developed in collaboration between Observatoire de la Côte d'Azur and Observatoire de Lyon. The modular structure of the design lead to four different cameras, with blue or red photocathodes, and with 100 images/s (i/s) or 262 i/s (Fig. 1).

The new low light level CCD technology (LLLCCD) has been evaluated. It has enough gain for photon counting operation (Basden et al., 2003). It contains an amplification register placed just before the readout amplifier, providing intensification of the charge packets by avalanches between electrodes of the register. J. L. Gach et al. (2004) tested such camera, and some experiments were made at OHP with LISE team, using Andor iXon cameras. We concluded this architecture is too much noisy for our low photon fluxes. Moreover, it is impossible to perform super-resolution: their photon events spread on only one pixel, preventing better precision by computing position of the photocenter. We concluded it is too early to use LLLCCD as photon counting detector in case of very low fluxes.

2 Hardware of CPNG-Algol cameras

CPNG-Algol photon counting cameras use two cascaded image intensifiers to provide enough gain, coupled by a lens to a commercial CCD camera. Data acquisition, on-line processing and storage are performed by a bi-processor PC.

2.1 Image intensifiers

Two image intensifiers have been selected for their high quantum efficiency: Hamamatsu V8070U-64 and ITT FS9910. The first one has a Ga As P photocathode sensitive to visible wavelengths (400 to 700 nm), and second one a Ga As photocathode sensitive to red and extreme red (600 to 850 nm). Both have a 18 mm diameter photocathode. Photocathodes are cooled down to $-15°$C for Ga As P and to $-30°$C for As Ga. This is done by 10 Peltier modules, their hot side being cooled by water circulation. A second intensifier stage, DEP XX1450VN, is used to provide enough gain.

2.2 Optical coupling

Image transfer between second intensifier output and readout CCD is fulfilled by a Rodenstock lens type HR-Heligaron. It reduces the image size to fit the CCD dimensions. Using a lens gives better image quality, without distortions and dislocations found with fiber optics reducers.

2.3 Readout cameras

Readout camera is screwed on the output side of the image transfer lens (C mount), allowing to change readout characteristics (speed, format) by changing CCD camera. Two commercial CCD cameras are used:

- Sony XC-HR300: 50 or 100 i/s, 782 x 582 pixels used on Algol cameras,
- Dalsa CA-D6: 262 i/s, 512 x 512 pixels used on CPNG ones.

3 Acquisition software

A bi-processor PC computer is used to control the camera and for data acquisition, on-line processing and storage. Photon events are detected, their positions measured with sub-pixel precision, and stored in real time. Other real-time data processing is performed for the applications: coherence tracking for interferometry, quick look for speckle interferometry.

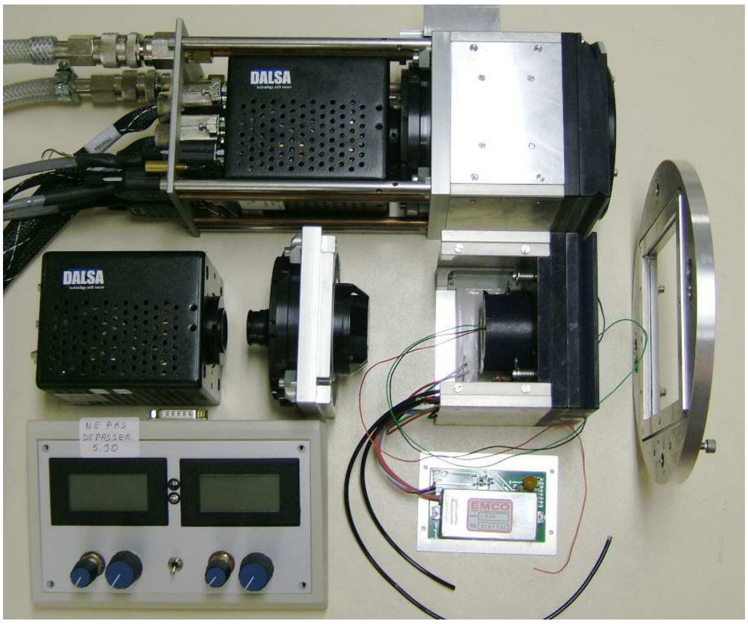

Figure 1: A CPNG camera and the elements of a second one. From right to left: fixation, image intensifiers, coupling lens, CCD camera. The intensifiers manual gain control is also shown.

3.1 Photon detection

Due to the large distribution of gain of the intensifiers stack, photon events have a large distribution of amplitude, the larger density being near the lower amplitudes. We must remove the image background to be able to detect faintest photon events. The background of CPNG cameras remains the same from line to line, but is fluctuating from frame to frame, so we should measure it on the fly during each image, then subtract it from the image. We can then detect faint amplitude events. Up to now, background subtraction is only implemented on CPNG cameras.

3.2 Photon localization and centroiding, super-resolution

The 3 x 3 pixels adjacent to a detected event are used to compute the position of its photocenter. This position can be computed with a precision better than the pixel size, limited by the microchannel spacing. A test on CPNG, with $1/20^{\text{th}}$ pixel centroiding (Fig. 2) shows the CCD pixels and the structure of the microchannel plate, with its holes. It provides the spacing of the channels: 6.2 μm. The size of CCD pixel projected on the input photocathode is 30 μm, so it is possible to perform super-resolution down to $1/5^{\text{th}}$ pixel.

3.3 Data storage

Photon events positions are stored with frame number. It is also possible to record the 3 x 3 pixels surrounding detected events, in order to perform centroiding off line, with slower but better algorithms.

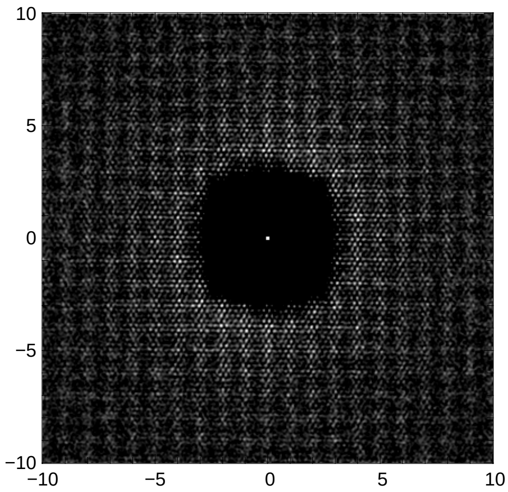

Figure 2: Central part of the autocorrelation of photon counting images with 1/20th pixel resolution. The structure of the CCD pixels can be seen, and the microchannel holes. The center part of the autocorrelation is dark because we cannot separate too close photon events. Pixel separation is shown on both axis.

4 Performances

Five photon counting cameras have been built, two Algol with Sony CCD and red and blue photocathode, and three CPNG with Dalsa CCD, red and blue photocathode. Performances have been measured on some of these cameras.

- Speed: Algol: 50 or 100 i/s, CPNG: 262 i/s.
- Image format: Algol R: 13.6 x 10.2 mm, CPNG: 15.3 x 15.3 mm.
- Pixel size: Algol R: 17.8 μm, CPNG: 30 μm (square).
- Distortions: 0,1 px, corresponding to centroiding errors. Measured by projecting a grid on the photocathode.
- Remanence: Algol @ 100 i/s: 3,3 % next image, 0 % 2nd next image; CPNG: 33 % next image, 0 % 2nd next image. Remanence is due to events which decay time overlap on two consecutive frames.
- Dark current: Algol R: 1000 e^-/s @ -30°C, Algol B: 750 e^-/s @ -15°C, CPNG R: 250 e^-/s @ -30°C.
- Dimensions: 110 x 110 x 292 mm for Algol, 110 x 110 x 317 mm for CPNG.

4.1 Quantum efficiency

Quantum efficiency has been determined using low light sources (stabilized light emitting diodes) at various wavelengths, measured with calibrated Si photodiode, and density. Fig. 3 shows the measurement points and the efficiency profiles from the manufacturers fitted to the measures. Thanks to background subtraction on CPNG, it has been pushed to 36 % in blue to green wavelengths, and 28 % in red ones. This important gain in sensitivity (compared to 10 % for CP 40 cameras) will open new objects to interferometric observation in visible wavelengths.

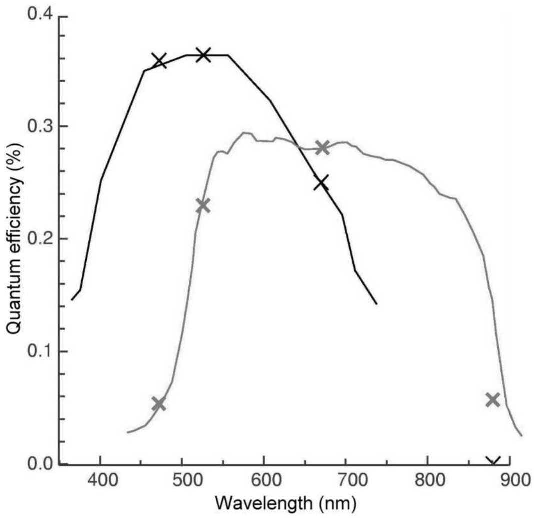

Figure 3: CPNG photon counting quantum efficiency (blue and red photocathodes). Crosses show the measures, curves are derived from intensifiers data and fitted to the measures.

4.2 Resolution

Photon event centroiding provides super resolution down to 6 μm, limited by the pitch of the microchannels. But for our present uses we need only 1/2 pixel resolution, which leads to 1564 x 1164 pixels for Algol and 1024 x 1024 pixels for CPNG.

5 Conclusions

This high quantum efficiency photon counting cameras come closer to CCD, without any read-out noise. With higher sensitivity new objects will be observable at visible wavelengths with interferometric techniques. For example we can reach P Cyg on GI2T or T Tau and Wolf Rayet stars with SPID.
Since mid 2003, both Algol cameras are used on GI2T-Regain interferometer. Two CPNG cameras will soon be used on SPID speckle interferometer.

References

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