



Status of AQUEYE, the fast multichannel photometer for the 182cm telescope at Cima Ekar



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In 2005 we designed a possible focal plane instrument (QuantEYE) for the 100 m Overwhelmingly Large Telescope (OWL) of the European Southern Observatory, as the fastest photon counting astronomical photometer ever conceived, with an array of 100 parallel channels, capable to push the time tagging capabilities toward the pico-second region. Thanks to this extremely high time resolution, and to the enormous photon flux at the output of the next generation of Extremely Large Telescope, it would be possible for the first time to study second-order statistical functions in the photon stream from celestial sources. To acquire real experience with such novel type of astronomical instrumentation, we are now in the process of realizing a small prototype (AQuEYE) for the Asiago 182 cm telescope. AQuEYE will have four independent photon counting channels. All the main building blocks of Aqueye are in the laboratory, in advanced status of verification and assembly. This paper will describe the main results obtained so far. As example of scientific programs we plan to tackle with it, we plan to follow the ingress and egress of extra-solar transiting planets, in order to determine with the highest accuracy the perturbation of the orbital elements to detect low mass unseen companions. This program is financed by the University of Padova, the Ministry of University and Research (PRIN 2006) and by the GALILEO Navigation Satellite System (GSA; Project Harrison).

1 The **optical configuration** of AQuEYE is essentially based on splitting the telescope aperture in four parts by means of a pyramidal mirror at the exit of AFOSC. The beams reflected by the pyramid are independently sent along four perpendicular direction and each of them is collimated by a first suitable lens system. At this position, where the beam is collimated, a filter/polarizer can be inserted. Then the beam is focused by means of a second lens system.

2 For the AQuEYE **performance estimation**, a 3 arcsec extended source, corresponding to more than the average seeing-limited size of a star at the Asiago telescope, has been assumed. After AFOSC, the pyramid and the lens train, the focus spot size is of the order of 40 mm (full width) and it is collected by a 50 mm SPAD (Single Photon Avalanche Diode) produced by MPD (Micro Photon Devices, Bolzano, I).

At the present status, the surface characteristics of the optics have been measured by means of interferometric techniques, showing that all the optical elements behave nominally. We are now performing the alignment of the four optical paths, using a CCD lab camera for monitoring the spot quality during the alignment activity. Only at the end of this activity, the SPADs will be integrated. The end of the optical alignment phase is estimated around the end of April.

3 **Detectors:** SPADs produced by the MPD company (Micro Photon Devices, Bz, I) will be used. MPD's single-photon detection modules have ultra-fast timing resolution, high photon detection efficiency (QE) and generate a TTL output pulse per detected photon. The evaluated QE is <60% at 550nm.

characteristics:
sensitive area 50 μm²,
dead time ~70 ns, time tagging capability better than 50 ps

Acquisition Mode: TDC board operate in two different modes: **continuous storage (CS)**, in which the absolute time is rolled-over every 52 μs; **trigger matching (TM)** where a trigger time tag provides a relative time reference (necessary when weak sources are observed, requiring long exposure (several hours) measurements)

4 The **electronics** of AQuEYE can be divided into four sub-blocks:

- 1) **detection system**, composed by 4 SPADs that convert the single photon detection events in NIM pulses;
- 2) **acquisition system**, performed by a Time to Digital Converter (TDC) able to time tagging the arrival of each NIM pulse from the detectors;
- 3) **pre-processing and storing system**, where a computer reads, in real time, data from the TDC board, and writes them into an external storage device;
- 4) **time system**, that assure a stable and accurate temporal reference to the time tags for both short and long time (time tag resolution is 25ps, precision required in long time scale is 100ps).

Instrumentation: 4 SPADs, CAEN board mounted on a VME crate; Optical bridge connects VME crate with a standard PCI board inside the controlling personal computer (PC) (maximum data-rate is 33 Mbytes/s). Data acquisition and board control is done by C++ using the CAENVME libraries. Future development foresees a statistics engine, running in parallel to the acquisition program. Acquired data will be initially stored on PC, for the real time statistical analysis, and then they will be placed on the external device (1 TByte) for a permanent storing.

5 To obtain a **time tagging** of photons arrivals with a jitter time inferior to 100 ps for 2-3 hours of measurements we are going to discipline the reference OXCO oscillator through a GPS dual frequency receiver to detect and correct frequency offset and long term stability using phase observable. A dedicated FPGA electronic must perform calculus for a real-time frequency correction through a Phase Lock Loop.

A sketch of the present instrumentation of INAF-OAC "Time and Frequency" laboratory is shown in the following figure. A Caesium clock (HP 5071A) is used as the master clock for the internal time scale, while a second clock is used as a back-up in the case of master failure. The time scale is then sent to the signal amplifier which distributes it around the laboratory, preventing some undesirable effects such as, for example, cross talks and others.

Using a dual frequency receiver we are able to determine in post-processing the phase displacement between two clocks connected to two AQuEYE instruments situated far from each other to realize **Hanbury-Brown Interferometry**. We can see in the three figure above the phase displacement determination with its standard deviation that is tens of picoseconds and the phase observable residual obtained, that are inferior to 1 cm.

6 A possible application of AQuEYE instrument is to study the **Transits of Extrasolar Planets**: The time between two consecutive transits (position 'b' in the figure) varies over time if the transiting planet is perturbed by another planet. In order to exploit such possibility, we need to repetitively observe for a large time span planetary transit with the purpose of obtaining accurate evaluation of the transit starting times.

For the very favorable case of an Earth-mass planet in 2:1 mean motion resonance of transiting a Jupiter-mass planet, the accuracy has to be at least of 1 min for about 1/2 year, where several tens of individual transit has to be observed.

Notice that we do not need an extreme precision of a single transit event (although a time resolved transit gives important information on the shape on the planets etc), but rather a good precision for a long time span (of the order of an year).

Another possible application could be polarimetric studies of transiting planets light curves.