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The optomechanical design of AquEYE, an instrument for astrophysics on its shortest timescales at the Asiago Observatory

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Abstract. This paper describes the ultra-fast photometer AquEYE (the Asiago Quantum Eye) being built for the 182 cm telescope at Cima Ekar, as a prototype for the QuantEYE instrument studied for the ESO OWL. In a way similar to what has been proposed for Quanteye, Aqueye isolates a single object at the center of the telescope field of view, and divides the telescope pupil in four parts. Each sub-pupil is then focused on a Single Photon Avalanche Photodiode capable to tag the arrival time of each photon to better than 50 picoseconds. The counts are acquired via a Time to Digital Converter board and stored in four separate memories. Both in-line and off-line algorithms will be available for data analysis. The designed optical non-imaging solution concentrates all the light collected inside a 3 arcsec field on the 50 micrometer detector square area. Different filters can be inserted in the 4 different optical paths. It is foreseen to utilize the instrument on several different astrophysical problems characterized by rapid variability, including occultations by the Moon, asteroids and KBOs, and extrasolar planet transits.

1. Introduction

The astronomical instrumentation usually exploits the spatial coherence (imaging) or the temporal coherence (spectroscopy) properties of the incoming photon stream. Beyond this first-order coherence, and encoded in the arrival time of each single photon, information lies about the details of emission mechanisms such as stimulated emission, or of subsequent scattering. We recall the classic paper by Glauber (1963) about second and higher order correlation functions (see Dravins et al. (2005), and Dravins et al. (2006) for further references on quantum optics concepts applied to astronomy). To explore this new realm of information carried by the light from astrophysical sources, it is necessary to corre-

Send offprint requests to: C. Barbieri late the times of arrival of the detected photons. To obtain significant results, the time resolution and time tagging capabilities of astronomical instruments must be pushed well beyond the current capabilities. Modern technology permits this order-of-magnitude improvement, as we have shown in the conceptual study of QuantEYE, a very high-time resolution astronomical instrument proposed for the OverWhelmingly Large (OWL) telescope of the European Southern Observatory (ESO) (Dravins et al. (2005), Barbieri et al. (2006), Naletto et al. (2006)). QuantEYE is capable to go into the yet unexplored domains of nanoseconds and beyond, sustaining GHz photon rates, thus approaching the domain of quantum optics. QuantEYE will have thus the power to examine the second order coherence function of photon arrival times, which increases with the square of the intensity (fourth power of the telescope diameter), implying an enormously increased sensitivity of the future Extremely Large Telescopes (ELTs), over existing telescopes. These capabilities will open detailed studies of phenomena such as variability close to black holes; surface convection on white dwarfs; non-radial oscillations and surface structures in neutron stars; photon-gas bubbles in accretion flows. Photon-correlation spectroscopy could also be performed, enabling spectral resolutions **R** exceeding 10^7. Moreover, given two distant ELTs, QuantEYE would permit a modern realization of the Hanbury Brown - Twiss intensity interferometer (Hanbury Brown (1974)). A more complete description of QuantEYE's capabilities for a very large spectrum of astrophysical problems is given in Dravins et al. (2005), and Dravins et al. (2006). Obviously, the QuantEYE conceptual design can be adapted to more conventional high-speed astrophysical problems, using even small telescopes. Here, we describe the main optical, mechanical and electronic characteristics of AquEYE, the QuantEYE prototype being built for the Asiago Observatory.

2. AquEYE, the first prototype of QuantEYE

QuantEYE was designed taking into account the characteristics foreseen in 2005 for the 100 m OWL telescope of ESO (details are given in Barbieri et al. (2006) and Naletto et al. (2006)). Although the final OWL design will differ from these adopted characteristics, the QuantEYE concept maintains its full scientific appeal, and can be easily adapted to different ELTs. We are currently realizing AquEYE (Asiago Quantum Eye), a first prototype of QuantEYE for the Asiago-Cima Ekar 182 cm telescope. This telescope offers us a good availability of observing time, and an excellent environment, from the mechanical shop, to clean areas, to control rooms. A further advantage of the 182 cm is the existing spectrograph AFOSC (Asiago Faint Object Spectrograph and Camera), which can be easily adapted to our goals. AFOSC (see Figure 1, its description is provided in `http://www.oapd.inaf.it/asiago/`) is mounted on a flange which takes care of many observational needs, from pointing and guiding to field vision and rotation.

A simple way to realize this prototype is by dividing the telescope pupil in four parts, by mounting a pyramidal mirror at the exit of AFOSC. The beams reflected by the pyramid are sent into four perpendicular directions, and each of them is imaged on a SPAD through a train of four commercial doublets (see Figure 2). Different filters and polarizers can be inserted in the parallel beam section between each objective, therefore giving the capability to define four independent photometers.

As detectors, we have selected the 50 μm SPADs (see Figure 3) produced by the MPD (Micro Photon Detectors, Bolzano, Italy) company. According to the data sheet, these detectors have the following characteristics: quantum efficiency in the visible band better than 45%, dead time around 70 nanoseconds, time tagging capability better than 50 picoseconds, afterpulsing probability less than 1%.

The optical performance of the designed system is excellent over the 50 micron detector active area, insuring an energy concentra-

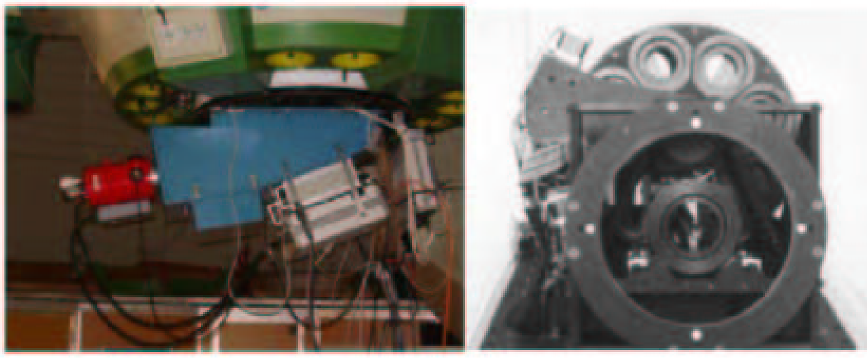

Fig. 1. Left panel: side view of AFOSC mounted at the f/9 Cassegrain focus of the 182-cm telescope. Right panel: the exit lens of AFOSC at the center of the mounting flange of AquEYE, which will replace the CCD dewar.

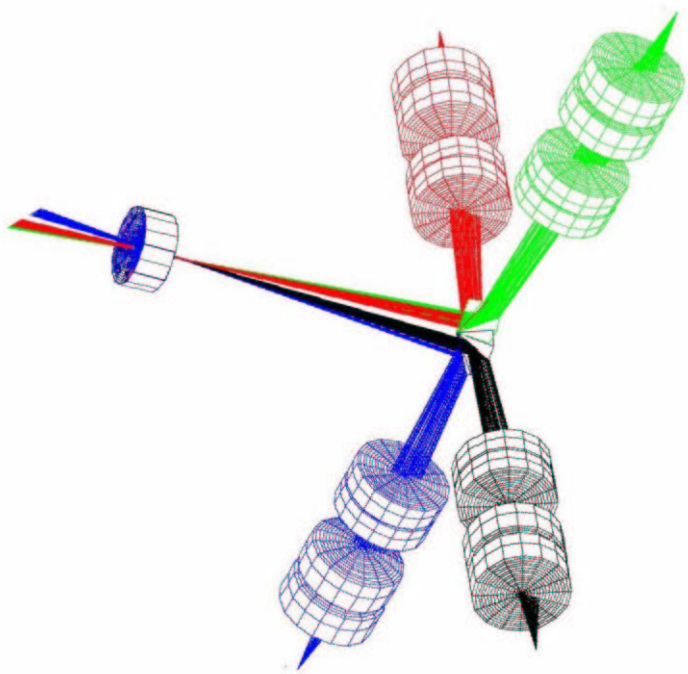

Fig. 2. Following the last lens of AFOSC, an aluminized pyramid splits the light into four separate channels imaged to each SPADs. Different filters and polarizers can be inserted in the parallel beam section between each objective.

tion from the blue (420 nm) to the red (700 nm) better than 90%, as shown in Figure 4. In order to take into account the average seeing conditions at the Asiago 182 cm telescope, the field of view has been increased to 3 arcseconds.

The AquEYE mechanical design is shown in Figure 5. Most of the pieces will be produced at the Cima Ekar workshop.

The electronics scheme is shown in Figure 6. The core of the electronics sys-

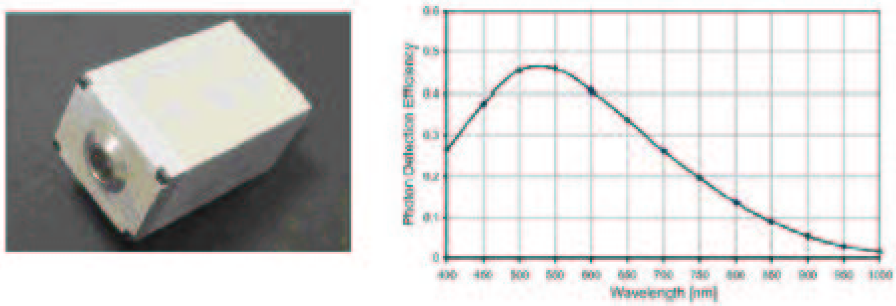

Fig. 3. The MPD SPAD characteristics. Left panel: each detector is lodged inside a thermoelectrically cooled box, with timing circuitry and NIM and TTL outputs. Right panel: the QE from the blue to the red.

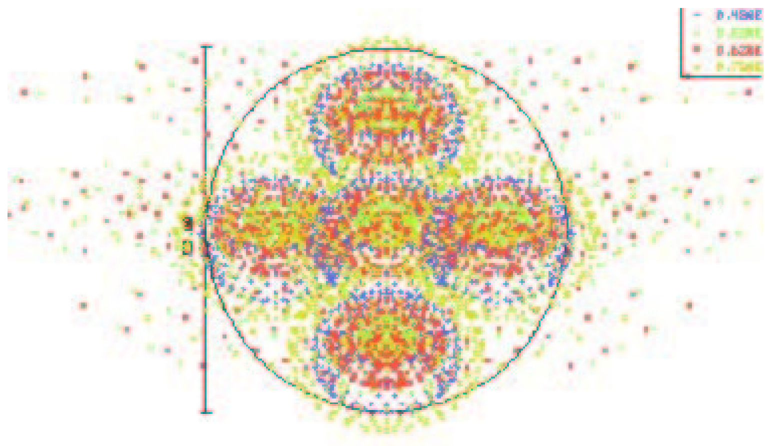

Fig. 4. The energy concentration between 420 and 700 nm, for five positions over the Field of View. The 50 μm circle is contained inside the square shaped sensitive area of the SPAD.

tem is a CAEN (Costruzioni Apparecchiature Elettroniche Nucleari S.p.A, Italy) Time to Digital Converter (TDC) board. This board will take the TTL inputs coming from the four SPADs and will process the signals. Each time tag will be buffered inside the board and then put into a standard VME bus. The TDC will be able to tag each event with a time precision of 35 ps per channel. As the electronics system will be attached to the telescope, the CAEN board will transfer all the time tag data to an external personal computer able to save each tag to a mass storage. The external computer will perform the a-posteriori data analysis, saving the interesting scientific data in some removable support for further studies. We now come to the crucial question of generating and maintaining a very accurate time for minutes and even hours. First of all, the start/stop commands will be tied to the UTC by means of the GPS (or the Galileo Navigation Satellite System, when available) signal, so that the data can be referred to a common time scale adopted by all telescopes on the ground or in space. We recall the scientific interest of correlations with X-ray and Gamma ray timing. However, we have to overcome the jitter that both for GPS and GNSS is at the level of ten nanoseconds or so.

The best internal clock is still under investigation, at present we plan to use a good thermostated quartz oscillator. Furthermore, we

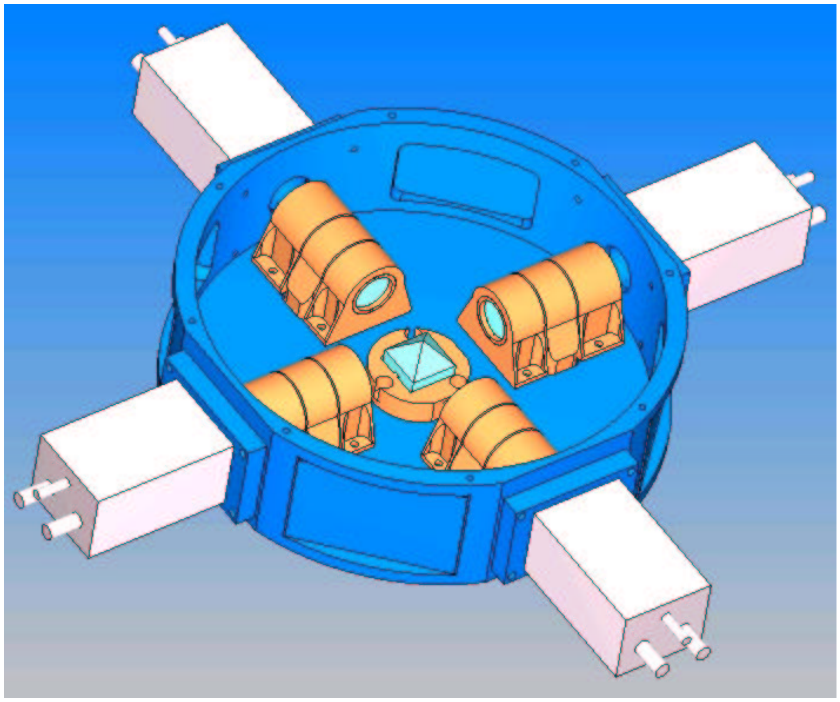

Fig. 5. The mechanical design of AquEYE. The pyramid at the center sends the light from the four subpupils to the four lateral SPADs, via four objectives composed of two pairs of doublets. The filter housings are shown in between the objectives.

shall perform experiments to tie to a common time reference, to better than 100 picoseconds, the clock in Asiago with a twin clock at the telescope Vega of Lubljana Observatory. This activity is seen as a practical demonstration of time distribution to very distant observers, in view of Very Long Baseline intensity interferometry.

3. Conclusions

AquEYE should be put in operation at Asiago toward the end of 2006. With this telescope, of modest size, we will not be able to achieve significant results on the quantum statistics of the photon streams from astrophysical sources. However, we plan to tackle with it several high time resolution astrophysical problems (occultations, cataclysmic variables, flickering and flare stars, exoplanet transits, and so on), taking advantage of the possibility of an a posteriori integration of the counts. AquEYE will be able to drastically improve the pioneering observations made in the past with fast photometers (such as MANIA); even a possible use in Optical SETI projects could be considered. Finally we will test the feasibility of synchronizing two distant observers and the time distribution between the two parties by using test sources such as the Crab Nebula, in view of future applications on larger scale telescopes in the quantum domain. The subsequent goal is to define an upgraded version to be brought to existing 8-10 m telescopes, such as the VLT or the LBT. In particular, the two mirrors of LBT would allow to perform a modern version of the Hanbury Brown - Twiss Intensity Interferometer, with a 100-fold improved sensitivity thanks to the augmented quantum efficiency, the much higher electrical bandwidth, the higher collecting area, the much superior optical quality of the telescopes.

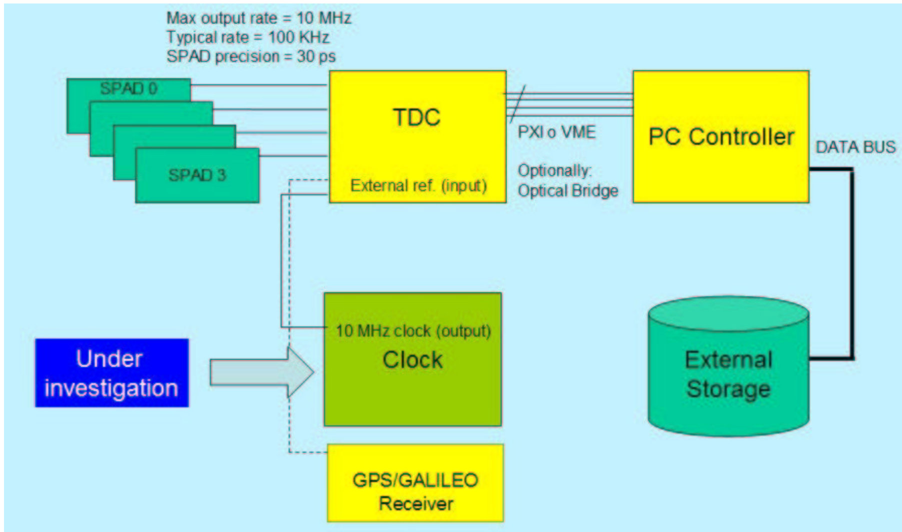

Fig. 6. The overall electronic scheme of AquEYE. The optimal internal clock is still under consideration.

4. Acknowledgments

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