Design and performance of the prototype Schwarzschild-Couder Telescope camera

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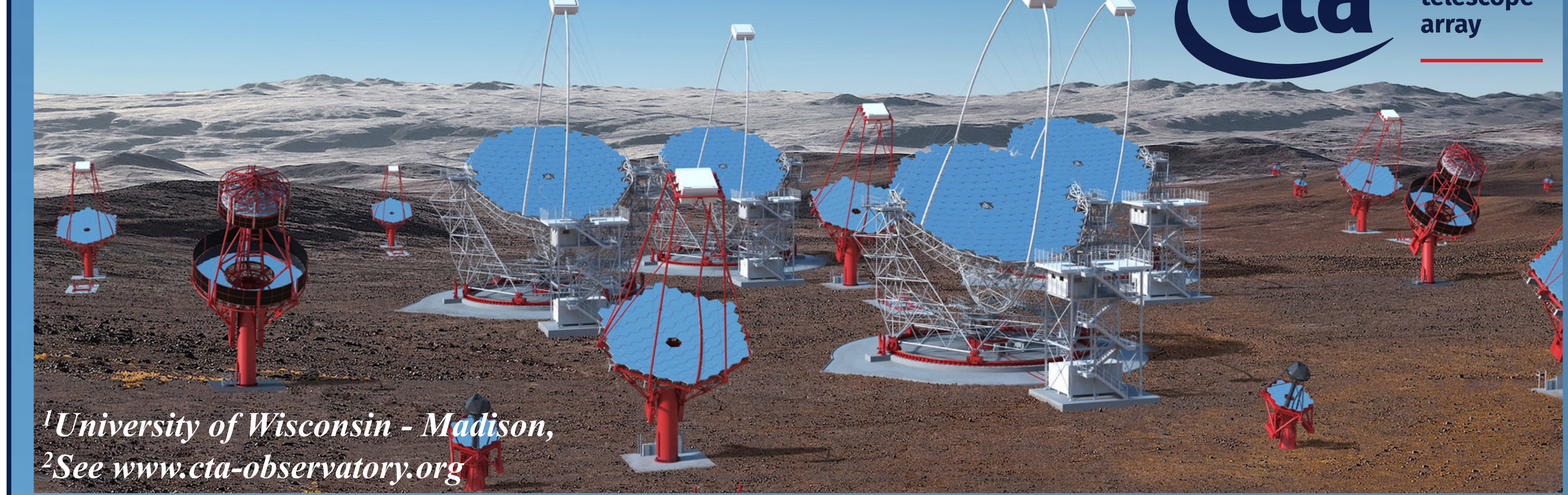
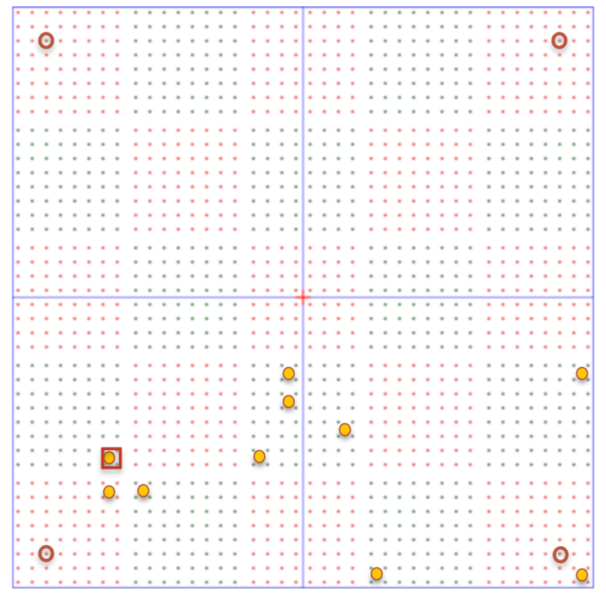


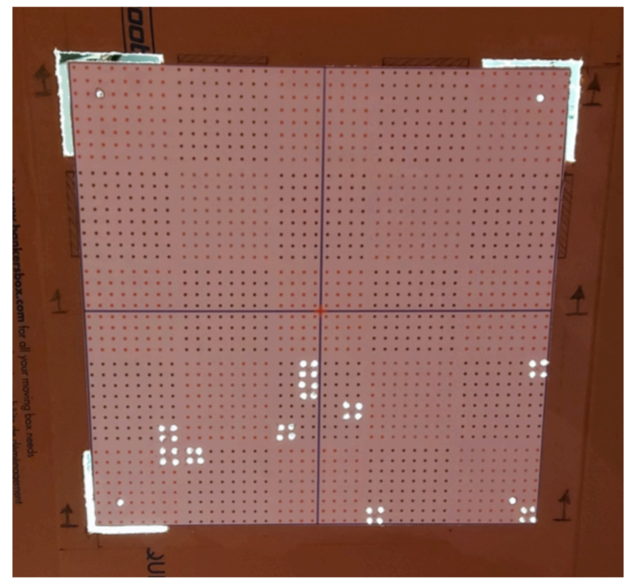
Validation of the Trigger Path

The module level trigger system monitors groups of 4 image pixels (called a trigger pixel) for a threshold crossing of their analog sum. If this value is crossed then a module trigger is sent to the backplane. If three adjacent trigger pixels produce a module trigger at the same time then the a backplane trigger is produced, prompting the camera to read out the event.

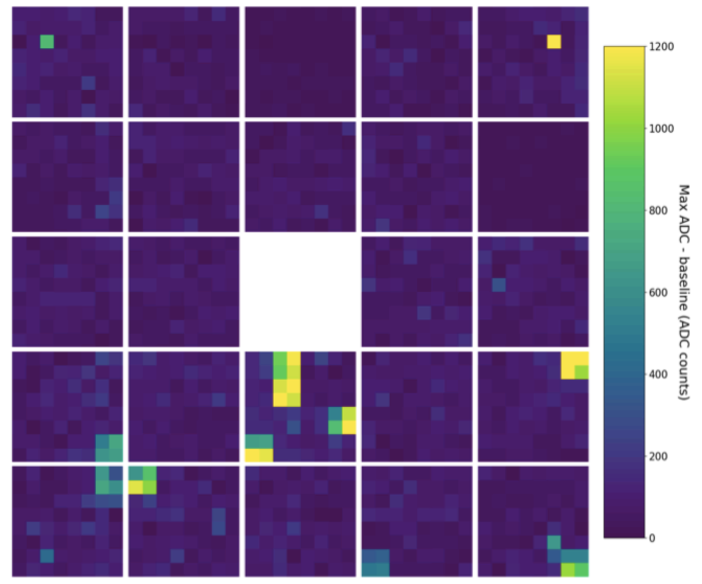
To validate this trigger system an asymmetrical cardboard mask was constructed, affixed to the camera focal plane, and illuminated with an LED flasher. The camera was allowed to internally trigger using 3-fold coincidence and trigger hitmaps were read out concurrently. A comparison between the mask pattern, data path and trigger path (Figure 1) shows that all three are consistent with one another.



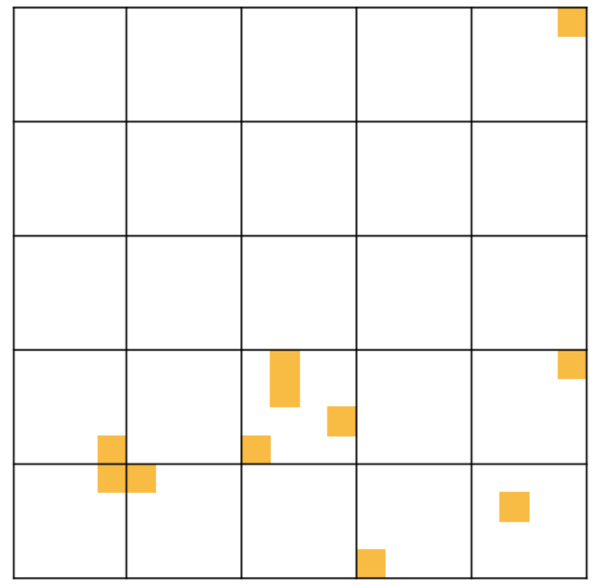
(a): *Image of the mask pattern. Only one group of trigger pixels is capable of satisfying the 3-fold coincidence required for a backplane trigger.*



(b): *The physical mask, constructed from cardboard, used to cover the focal plane. Each hole is in the center of an image pixel.*



(c): *Event image taken with camera mask installed on the camera. Uncovered pixels are clearly brighter.*



(d): *Trigger hit map pattern read out concurrently with event image. Pixels which triggered are shown in yellow.*

Figure 1: *An asymmetric cardboard mask was constructed, attached to the camera focal plane and illuminated with an LED flasher. Event images from the data path and hitmaps from the trigger path both match the mask pattern, confirming trigger mapping in the camera.*

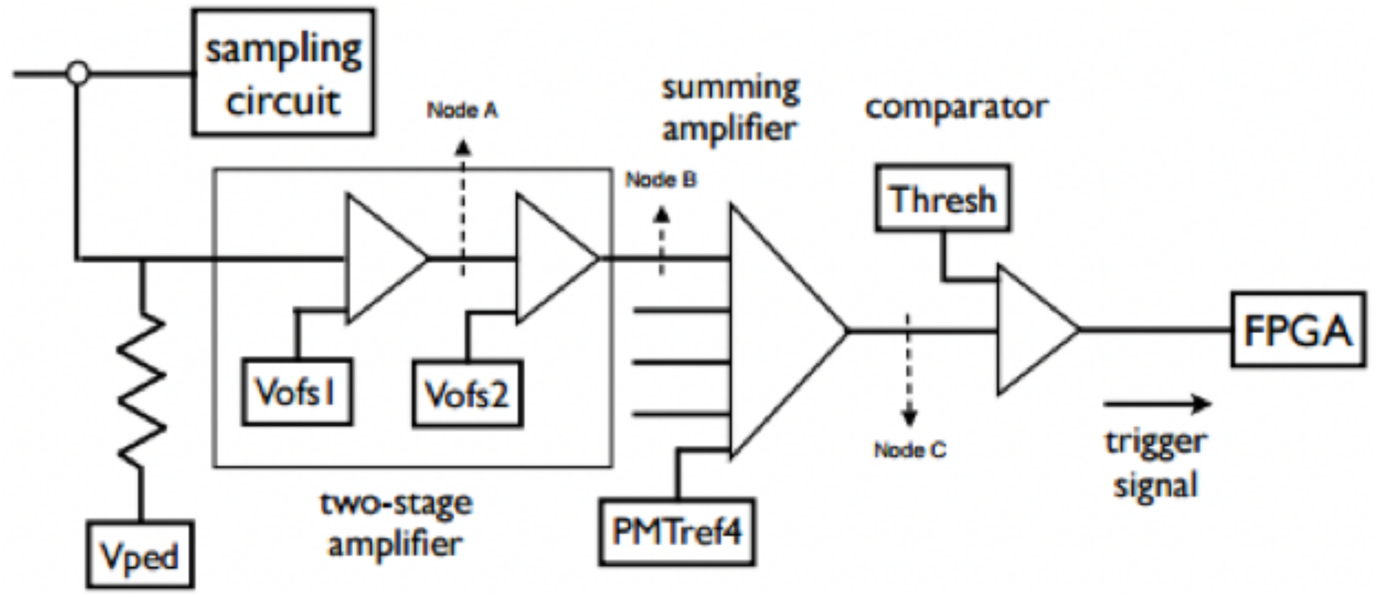


Figure 2: *A circuit diagram for one trigger pixel. Four image pixels are amplified individually via two inverting amplifiers (with Vofs1 and Vofs2 as reference) and then combined in an inverting summing amplifier (with PMTref4 as reference) to produce the signal for one trigger pixel. The target output of the summing inverting amplifier has been changed from 1.25 V to 2.1 V.*

Temperature Dependent Trigger Tuning

The reference values for the trigger circuit (shown in Figure 2) are tuned such that the output is 2.1 V when the signal is at nominal baseline. Reference values are temperature dependent. This was mitigated by implementing temperature dependent trigger tuning. Individual module temperature is determined prior to each data run and appropriate reference values are used.

Improving Dynamic Range

Originally, the baseline output of the summing amplifier (Node C in Figure 2) was 1.25 V (the center of the output range). However, signals into the summing amplifier are unidirectional meaning half of this dynamic range was not being used . The baseline output was changed to 2.1 V (the highest value at which the summing amplifier maintains linearity). This change effectively extended the dynamic range for our expected signal. Figure 3 shows the improvement to our dynamic range.

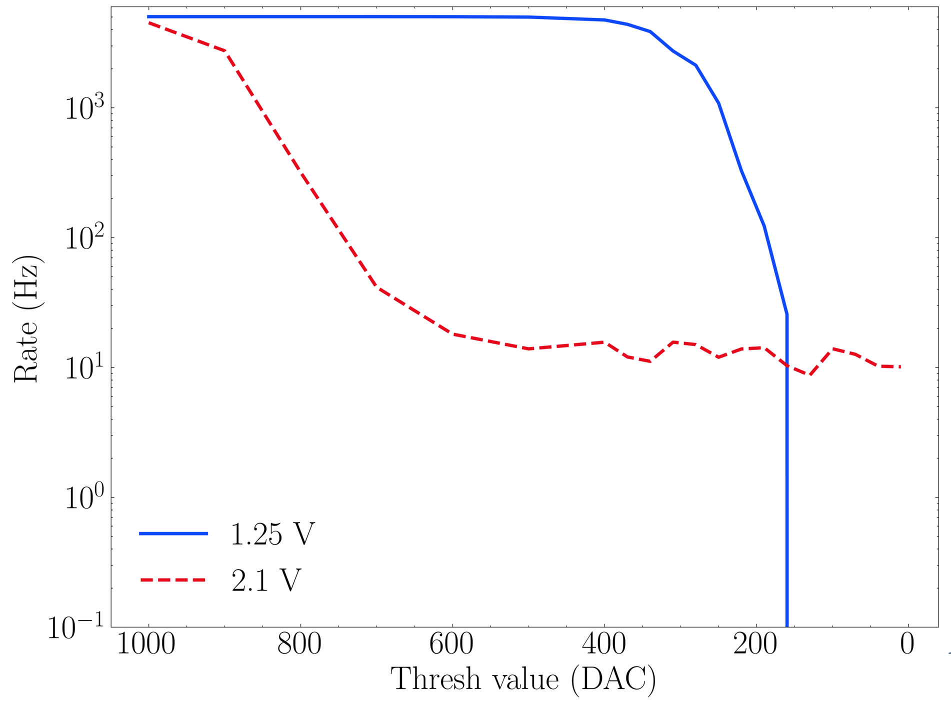
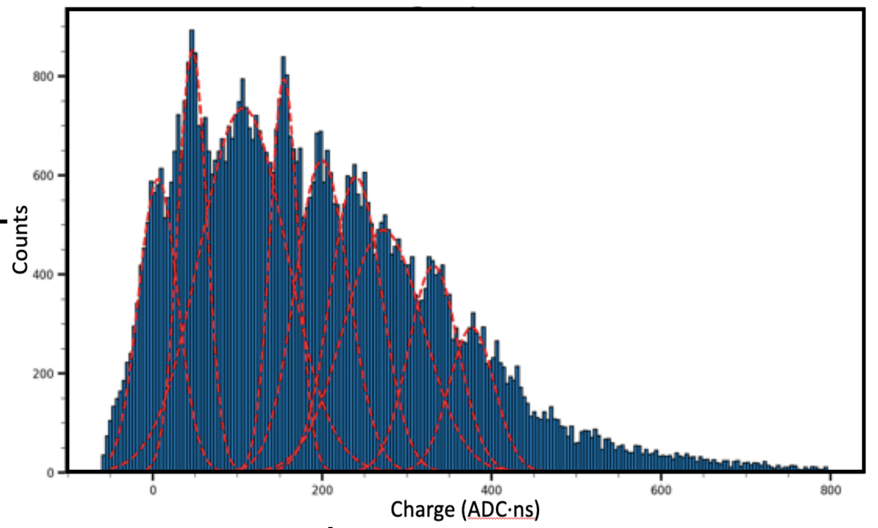


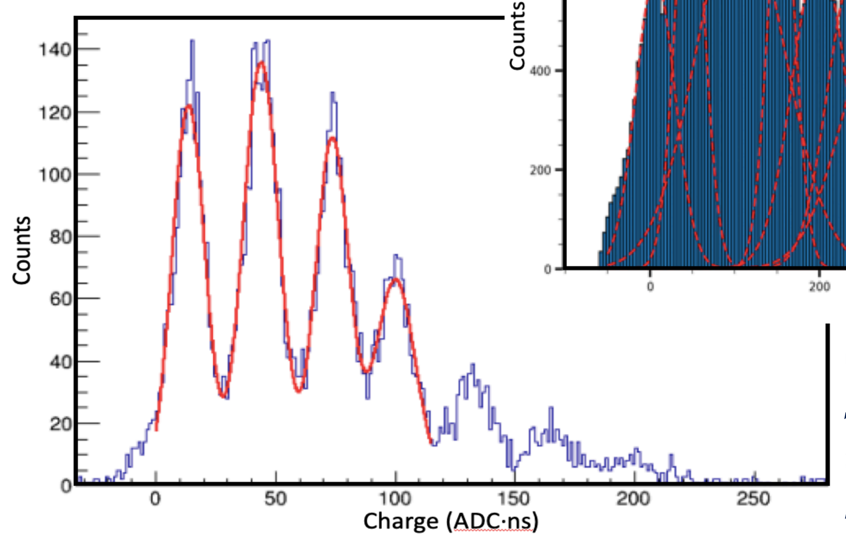
Figure 3: *Rate scans, comparing Thresh value to the trigger rate. Both scans were taken with a flasher running at 100 Hz. The new desired output value of 2.1 V shows a significant improvement in the dynamic range, clearly showing the flasher plateau at 100 Hz.*

Including All Modules in the Trigger

Currently the camera includes two types of SiPMs – Hamamatsu (US) and FBK (INFN). These SiPMs have different gains and thus the conversion between Thresh (see Figure 2) and photoelectrons are different. This difference in threshold meant that for the same Thresh value INFN modules would dominate the trigger. This fact, along with the geometry of the camera (in which INFN modules are located at the edge of the focal plane) meant that it was beneficial to exclude the INFN modules from the trigger during initial observations. In an effort to update the trigger to include INFN modules the Thresh to photoelectron conversion was found for both module types. However, there is no threshold at which both types can be included in the trigger at the same photoelectron value. Rather than continue to leave INFN modules out of the trigger it was decided that they would be included at a Thresh value which keeps them subdominant to US modules (at approximately 1/10 the trigger rate of US modules). The INFN modules were included in the trigger starting 17 March 2021.



(a): Right plot. *Charge spectrum produced from current modules using Hamamatsu SiPMs.*



(b): Left plot. *Charge spectrum produced from upgraded modules using FBK SiPMs.*

Figure 4: *The upgraded modules have lower noise and show a significant increase in the charge spectrum resolution.*

Camera Upgrade

The camera upgrade will include an upgrade to the camera module SiPMs and front end electronics. Figure 4 shows the charge distributions of current and upgraded modules, illustrating a significant increase in resolution. Additionally, the focal plane will be fully populated with these upgraded modules increasing the number of pixels from 1600 to 11,328 And the field of view from 2.7° to 8°.

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