Flare Star Observations with a Single-Photon Counting Imaging Detector

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Abstract: At Los Alamos National Laboratory we are developing a new imaging sensor which combines high spatial and high temporal resolution over a large area format, while maintaining single-photon counting sensitivity and sustaining a high count rate. The detector is called a microchannel plate with crossed delay line readout, or MCP/CDL. This detector is ideally suited to the observation of weak transient events, such as stellar flares from red dwarf flare stars in our Galaxy. At present we are initiating an experiment with the MCP/CDL detector which will utilize a 30-cm aperture f/7 telescope to characterize U-band, B-band, and V-band emission from such low-luminosity flare stars, and to search for weak optical transients associated with other astrophysical sources.

1 The MCP/CDL Detector

Over the past several years, new photon-counting microchannel plate imagers have been developed that allow the location and time-tagging of individual photons with high accuracy (Baron & Priedhorsky 1993). The newest version utilizes a crossed delay line for readout of individual photon events, and so it is designated as an MCP/CDL detector.

The current MCP/CDL design uses a transmissive S-20 visible photocathode deposited on the inside surface of the vacuum window of the detector. Photoelectrons emitted from this surface are accelerated across a narrow gap to the 40-millimeter active diameter microchannel plates in a z-stack (three plates in series) configuration, providing an electron gain of 10^7. Each incident photoelectron on the front surface of the stack generates a cloud of electrons out the back that passes through a pair of orthogonal helical windings – one in the X-direction and the other in the Y-direction. Readout of each photon is accomplished by precisely measuring, at the ends of each delay line, the time difference of arrival of the electron-cloud induced pulses.

The maximum photon counting rate available from the detector is presently one-half million per second, limited by pileup of events on the 100-ns long delay lines. Within a few months a new front-end electronics package will boost this rate to approximately five million photons per second. The demonstrated spatial resolution in our prototype detector is better than 20 microns, corresponding to

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a 2000×2000 pixel circular format. Background count rates from this uncooled detector are approximately 100 counts/second at room temperature, out of the $5 \cdot 10^5$ counts/second overall.

The output of the detector's electronics is in digital format. Photon events are stored as X and Y positions plus a time tag. This enables us to reconstruct images from photons integrated over long exposures, and to remove any effects of apparent image motion, and to correct for the non-uniformities associated with each detector. It also permits us to easily examine the time history of the photons arriving at any given pixel. Data are stored on multi-gigabyte disk pedestals during observations, and then transferred to mass storage devices for later analysis.

2 Application to Flare Star Observations

This detector is well suited for the observation and characterization of magnetically active red dwarf flare stars which, in addition to their quiescent output, randomly emit copious quantities of broadband electromagnetic radiation. Observations are typically made in the U-band or B-band to provide the greatest contrast between quiescent and flare output. These flare stars are relatively common in the Galaxy (Mirzoyan 1990), with an estimated density of around 0.01 pc^{-3}. Recent calculations suggest that the density of flare stars in the solar vicinity is several times higher than that value (Mirzoyan 1995, Shakhovskaya 1995). A typical value of U-band energy released in a flare is 10^{32} ergs. Previous calculations have shown a relationship between the rate of flaring and the energy released in the flare (Gershberg and Shakhovskaya 1983). That relationship is

$$R(> E_{U32}) = 10^{-2}(E_{U32})^{-0.75} \tag{1}$$

where R is the rate (hr^{-1}) of flares with energy greater than E_{U32}, and the quantity E_{U32} is defined as the U-band energy in units of 10^{32} ergs. From this relationship it is evident that the weaker the flare energy one can observe, the higher the rate at which those flares will be observed, and the best statistical results will be obtained from a detector which can image very weak flares from low luminosity flare stars. The MCP/CDL can do this, and it should provide an improved observational value for the density of flare stars in the solar vicinity.

Under moonless and cloudless observing conditions at viewing angles near the zenith, the background photon count rates in the U-band (O'Connell 1987) correspond to an average of a few tenths of a count per pixel per second with our MCP/CDL detector placed at the focal plane of our telescope. This is equivalent to a $U = 19$ star in each pixel. A flare event which generates photons at a rate that is statistically significant against this background, for example 20 photons over 20 seconds in a given pixel, will contribute to our survey.

The minimum detectable energy of a flare is a function of distance. In the U-band our MCP/CDL detector and 30-cm telescope should detect a flare of $3.5 \cdot 10^{30}$ ergs at a distance of 100 parsecs, and one of $3.5 \cdot 10^{28}$ ergs at 10 parsecs, both of which correspond to recording 20 photons. The expected flare

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rate seen by our detector is obtained by integrating out along the 1°1 FoV of the telescope. Our U-band calculations show that, assuming the 20-photon observational threshold, event scaling according to equation (1), and a flare star density of 0.01 per cubic parsec, flares should be detected at a rate of several per hour, when viewing a general galactic field.

3 Current Status of the Experiment

At the present time we have one working version of the MCP/CDL detector. As a result of a degraded photocathode response due to some suspected high-voltage breakdowns over time, this unit is sufficiently insensitive that it cannot be used for routine flare star survey sessions. A few images, however, were obtained with this unit in the summer of 1994 using a 15 cm aperture refractor telescope and with an 18 cm aperture Questar telescope. These images have provided verification of background counting rates, as well as a data base with which to develop the algorithms necessary for image reconstruction. One example of a V-band image obtained in a July observation is shown in Fig. 1. This exposure was integrated over 400 seconds with the fixed refractor telescope. The resulting raw image shows streaks corresponding to the apparent motion of the stars. This motion has been removed in software, and the integrated stellar images are as shown in the figure. Some inherent non-uniformity in the present detector's response has not yet been removed from this image. The two remaining streaks in the image were generated from fixed hot spots in the detector that were spread out during image reconstruction.

At the present time we also have a small amount of data obtained in the U-band, taken with the 18 cm Questar telescope. It is sufficient to verify background photon counting rates for comparison to theoretical values. We do not yet have sufficient data to begin any search for flare events. That search will begin with our acquisition of a new detector and telescope in early 1995.

4 Observation Schedule

We are presently awaiting delivery of a new telescope that has been designed specifically for the flare-star project with this MCP/CDL detector. The modified Ritchey-Chretien optical configuration has been designed to provide a flat-field image over the 40-millimeter diameter of the MCP/CDL detector for the U, B, and V bands. Its aperture is 30 cm and the focal ratio f/7. These values have been selected in order to match the maximum photon counting rate capability of the MCP/CDL electronics, where it operates at highest efficiency. The angular resolution will be 2″. This telescope is under construction, and due for delivery in January, 1995. We also expect delivery of a new MCP/CDL detector in March, 1995. Observations will begin soon thereafter, at a remote site in the Jemez mountains located thirty five miles from Los Alamos National Laboratory.

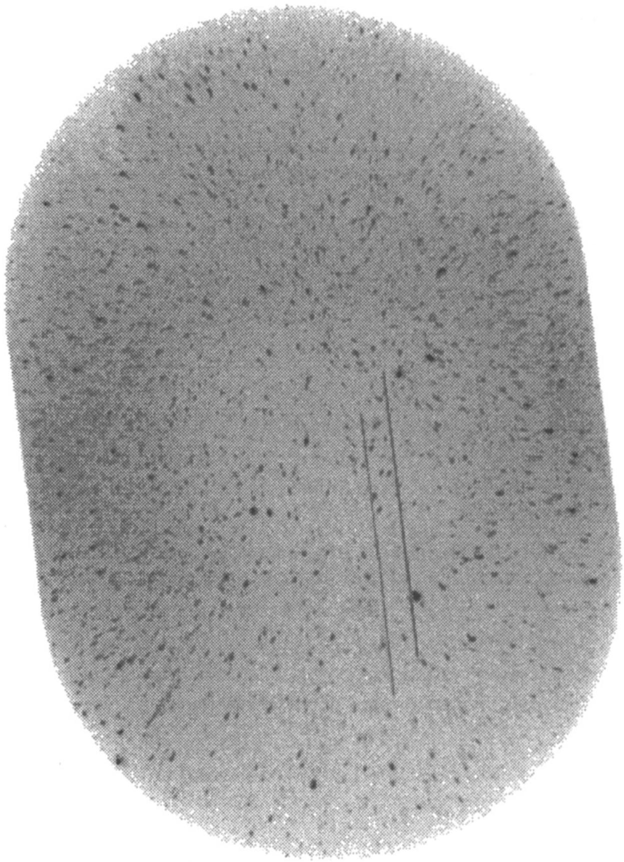

Fig. 1. V-band stellar image from the vicinity of the constellation Lacerta obtained with the MCP/CDL detector. Exposure time was 400 seconds. Apparent stellar motion has been removed in software leaving two detector hot-spot streaks (see text).

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