Final Report

DEVELOPMENT AND TESTING OF AN IMAGE TUBE CAMERA AND SPECTROGRAPH

By: ROBERT L. SHARPLESS

Prepared for:

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
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CONTRACT NASr-49(26)

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SRI Project PAU-6376

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ABSTRACT

This report describes a camera-spectrograph combination in which an image intensifier tube is used for increased light sensitivity. This unit was used to observe an artificial aurora generated by a rocket-borne electron accelerator. The trajectory of the rocket departed considerably from the intended trajectory, so that ground observers had no accurate pointing information. Experimental apparatus was misdirected, and no auroral signal was observed. Identification of stars in the field of view shows that stars to a magnitude of 8.6 or below can be detected. This should be sufficient sensitivity to observe auroral rays that fall within the field of view of the camera-spectrograph.

Introduction

At 4:45 EST on the morning of January 26, 1969, an Aerobee Rocket was launched by NASA from Wallops Island, Virginia. The principal part of the payload consisted of an electron accelerator that was capable of producing beams of electrons of 500 ma at 10 kV for one second. The accelerator was oriented so that the electrons were shot down the earth's magnetic field lines and followed them into the earth's atmosphere. The purpose was to determine the feasibility of exciting an artificial aurora of sufficient intensity to be observable. If the technique is feasible, it has many applications, the most obvious being conjugate point mapping. In addition to optical observations, radar and VLF radio studies were attempted. Groups involved in the program were NASA Goddard Space Flight Center; NASA Wallops Station; NASA Manned Spacecraft Center; U.S. Naval Research Laboratory; U.S. National Security Agency; Ion Physics Corporation; Lockheed Palo Alto Research Laboratories; Smithsonian Astrophysical Observatory; Stanford Research Institute; Geophysical Institute, University of Alaska; Radio Science Laboratory, Stanford University; School of Physics and Astronomy, University of Minnesota; and The Johns Hopkins University.

The contribution SRI hoped to make was to show the feasibility of using an image intensifier tube to obtain pictures and spectra of the auroral rays. This report covers only the work done by SRI.

Objective

The principal objectives of SRI's research effort were: (1) to develop a combination camera-spectrograph, using an image intensifier tube, to observe low luminosity sources; and (2) to provide the necessary qualified personnel, materials, and equipment for operation of the image tube camera-spectrograph in support of the NASA electron beam field mapping experiment.

Development

During the early stages of development, it became obvious that several basic conditions needed to be met in order for the data to be meaningful:

1. The camera-spectrograph needed to be on a steerable mount.
2. Time and look angles needed to be recorded.
3. Sufficient identification needed to be put on the film so that the time and look angles for each picture frame could be obtained for correlation with other data.
4. Most of the optical phenomena to be observed were expected to last about 1/10 of a second, approximately every tenth one lasting for 1 second.

After considering the experimental parameters, among them the 1/10-second normal pulse length, the 7/10-second radiative lifetime for the oxygen $O(^1S)$ state that was expected to be one of the prominent features of the 1-second signature pulses, and the very low luminosity of the phenomena to be observed, it was decided that the film transport must operate at controllable speeds up to at least 10 frames per second with a shutter closed time between frames of less than 50 msec.

It was found that the best method of recording the time and look angle (and also the least expensive) was to record this information directly on the film. Since we did not have a film transport that would even come close to meeting the above requirements, it was necessary to obtain a new one. Obtaining one with a special data box in which we could display time and look angles was no problem.

Finding a steerable mount that could be adapted for our needs was more difficult. Since we planned to send only two men to the field, it was necessary that the equipment be easily broken down into units that two men could handle and set up. The available mounts that had sufficient capacity to handle our equipment were much too heavy. It was finally decided that it would be most satisfactory to build one similar to the ones built by T. Neil Davis' group at the University of Alaska.

The most difficult element of the system to design was the lens used to relay the picture from the output phosphor of the image intensifier tube onto the film. There were several restrictions on this lens. First, it had to have a high relative aperture. Second, since the phosphor is on the inside of a glass window that would introduce noticeable spherical aberrations into an uncorrected high aperture lens, the lens had to be corrected for looking through a face plate of the proper thickness. Third, since the shutter on the camera is about three quarters of an inch in front of the film plane on the film transport, the back focal length on the side toward the film transport had to be at least this long. Since no lens was available that would meet the requirements for both image tube side and film transport side, it was necessary to use an unsymmetrical lens composed of two different standard lenses coupled together. Many compromises had to be made. The lenses used were a 3-inch f/0.87 Super Farron on the image tube side and a 2-inch f/0.95 Angenieux on the camera side.

The luminous trail ("auroral ray") produced by the electrons was expected to be confined to a narrow streak as viewed from the ground. It should therefore have been possible to get a spectrum by inserting a grating in front of the camera. However, since the light is diffracted by the grating, some compensation had to be made in the optical path or in the pointing angle of the instrument when the grating was inserted in order to keep the same field of view. Figure 1 is a diagram of the camera layout. Two mirrors were inserted in front of the grating to change the line of sight by an amount equal to the diffracted angle for the diffraction grating for about 600 nm. The mirrors and the grating were mounted on a carriage that ran on ball slides so that the camera could be easily and quickly converted to a spectrograph. The field of view of the spectrograph is different for each wavelength. Since the angular difference between opposite ends of the spectrum (400 nm to 800 nm) is almost as large as the field of view, good pointing accuracy would be required to get a good spectrum. The completed instrument is about 4 1/2 feet long, 2 1/2 feet wide, 1 1/2 feet high, and weighs about 175 pounds.

Field Site

The field site was on the grounds of the U.S. Department of Commerce Fisheries Station at Franklin City, Virginia, about 20 km north of the launch site. The equipment was housed in an 8 foot square, open-top plywood shelter. The top of the shelter was covered with a tarpaulin that was rolled back for observing. This shelter was about 15 feet from the University of Alaska instrument van. We were tied into their van for communications and time signals.

Results and Conclusions

Look angle tables for various observing stations, covering a wide variety of possible trajectories, were prepared in advance by E. G. Stassinopoulos of Goddard Space Flight Center. The nominal flight plan called for a trajectory with a peak altitude of 295 km and an impact point 98 km from the launch pad at an azimuth of 162°. Because of a deviation in the performance of one of the rocket engines, however, the actual trajectory was well outside the limits that had been expected: the rocket achieved a peak altitude of 269 km with an impact point only 50.4 km from the launch pad at an azimuth of 97°. No accurate look-angle tables were available to any of the observing stations for this unexpected orbit. As a result, none of the auroral rays occurred within the field of view of our camera.

During the rocket flight the transport was operated at 10 frames per second. On this film transport the shutter is closed for about 35 msec between frames, so that the actual exposure time is about 65 msec. At the start of the experiment the Oude Delfte f/0.75, 105-mm objective lens was stopped down to f/1.4. After the first signature pulse it was opened up to f/0.75 and run there for the rest of the experiment. The relay lens system included a periscope which allowed visual monitoring of the output of the image intensifier tube. Since no auroral rays were seen visually on the output of the image intensifier tube, no attempt was made to obtain spectra.

Figure 2 is a comparison of the field of view of our camera with the location of the auroral rays for the first 4 signature pulses. It is clear that none of these pulses occurred within the field of view of our camera. Prints were made of our pictures taken at the time of the signature pulses and of many of the other pulses of reasonable power (5 kV at 500 ma; 10 kV at 150 and 500 ma). These were examined for auroral ray tracks but none were found. When information on the actual location of the rays became available, comparisons between our field of view and the known or calculated position of the signature rays were made using the star field as a reference. We conclude that none of the auroral rays were in our field of view.

Figure 3 is representative of the data we obtained. The line on the left was drawn in, to indicate the location of the auroral ray that occurred during the time the exposure was made. The field of view is indicated by the gray region. The black spots are stars (the large ones being "burned in"). The gray background is caused by the night airglow. The field of view is not sharply defined, since it is determined by some of the optical elements and not by an aperture at the film plane. The large dark patch at the top of the field of view is due to scattered light from equipment pilot lights or electric heaters in the instrument shelter. It only occurred for a limited range of look angles. It was not detected during the installation and checkout of the camera and disappeared during the late phase of the experiment when the camera was pointed to the south. The black bar that is visible in the middle of the patch is the indicator for the adjustable iris diaphragm on the objective lens; the length of the bar is proportional to the opening of the iris. The lens was wide open at the time this picture was taken. The numbers in the upper right-hand corner are auxiliary data. The top number is the elevation angle in tenths of a degree. The dark spot between the first and second number is the "beam on" light that indicates when the pulses occur. The second number is the azimuth angle in tenths of a degree, and the bottom number is range time in minutes and seconds.

In order to determine the sensitivity of the camera, we looked up the magnitude of some of the faint stars that were recorded. We are fairly sure of the identification of some stars as faint as 8.6 magnitude. Two or three of the stars were identified (by their location) as stars having magnitude of about 9.0; however, since other stars of magnitude 8.7 to 9.0 that were in our field of view were not seen, there is some question about the identification of these very weak stars.

From the pictures of the auroral rays taken by Davis,[1] we estimate the rays would have had a density on the film equivalent to a star of 8.5 magnitude. This would have been detectable on our pictures if it had been within the field of view.

The camera was operated from a few seconds before the expected start of the pulses until a short time after the last pulse. The performance of the equipment during the experiment met all our expectations. The steerable mount, while not as solid as a heavier one would be, was adequate for our needs and easy to operate. All the auxiliary data was successfully recorded on the film as shown in Figure 3. The resolution on the film was about 70 μm, i.e., about .06 degree of arc or about 120 meters at the 120 km range at which the auroral streaks occurred.

Recommendations for Future Work

In view of the problems in knowing the correct look angles during this experiment, and since it was proved that visual tracking of the auroral streaks is not practical, a computer needs to be available to take the trajectory information from range tracking in real time and compute expected auroral streak locations at least several seconds in advance which can be relayed to the ground observers.

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[1] Gilbert D. Mead, Jaylee M. Mead, and T. Neil Davis, "Artificial Aurora Experiment: Position Measurements of Auroral Rays and Comparisons with Predictions," Report No. X-641-69-221, Goddard Space Flight Center, Greenbelt, Maryland, June 1969.

Since the night airglow background was detected during this experiment, any possible increase in optical speed would not result in a smaller minimum detectable signal. The only way to lower the minimum detectable signal is to improve the resolution. This will give a better signal to noise ratio for small images such as the auroral rays expected in this experiment.

We have at SRI a spectrograph that utilizes an all-reflecting objective lens of the same focal length as the transmission one used for this experiment, which has much better resolution than can be obtained with transmission optics. It is coupled to an image intensifier tube. The resolution as measured at the output phosphor of the image intensifier tube is about twice that obtained with the transmission lens image intensifier tube combination when the lens is operated at full aperture. Although this system is larger and heavier than the transmission system, these disadvantages can be overcome. This spectrograph would be our choice for use on the next artificial aurora experiment.

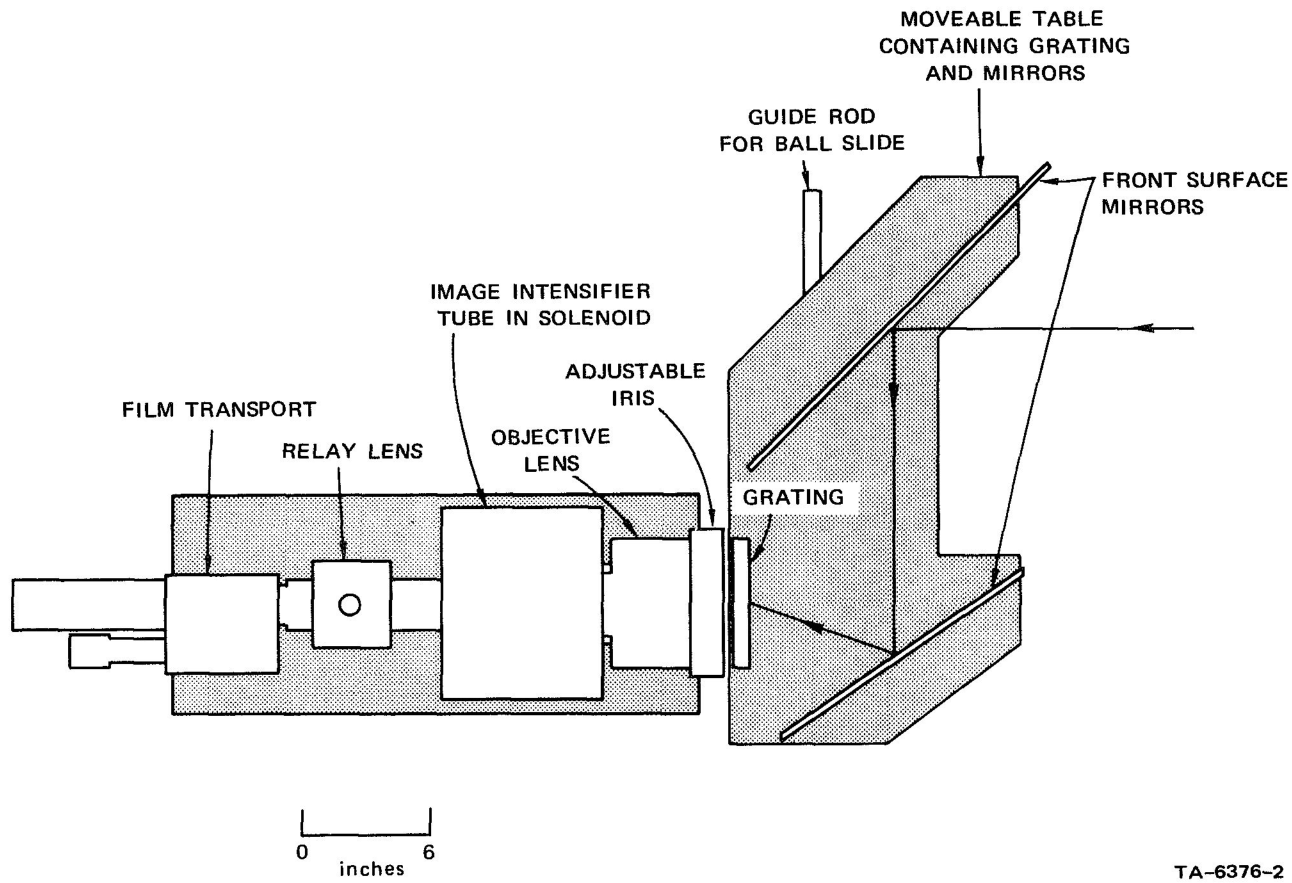

FIGURE 1 SCHEMATIC LAYOUT OF THE CAMERA-SPECTROGRAPH

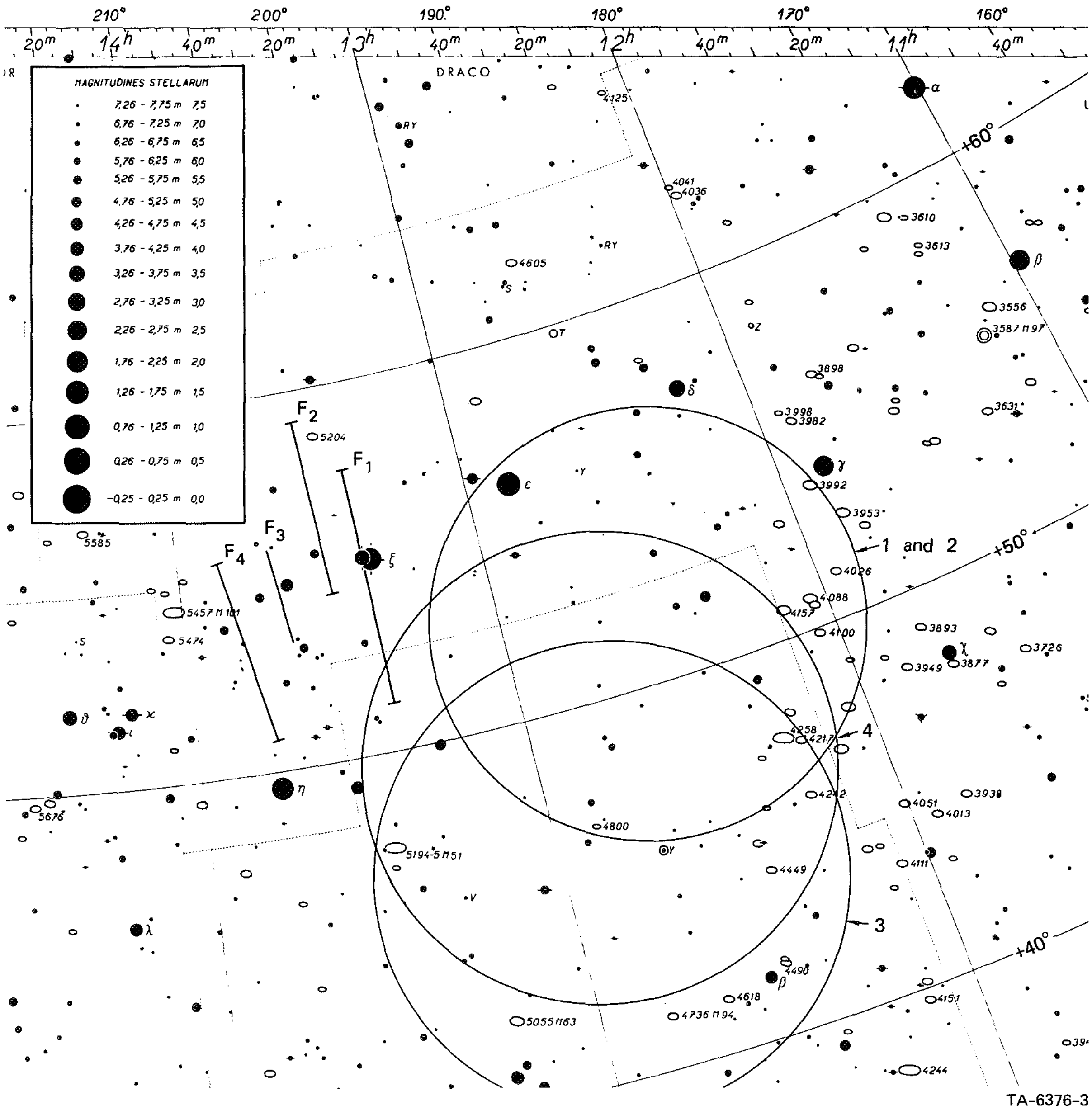

FIGURE 2 COMPARISON OF THE FIELD OF VIEW OF OUR CAMERA WITH THE LOCTION OF THE AURORAL RAYS FOR THE FIRST 4 SIGNATURE PULSES

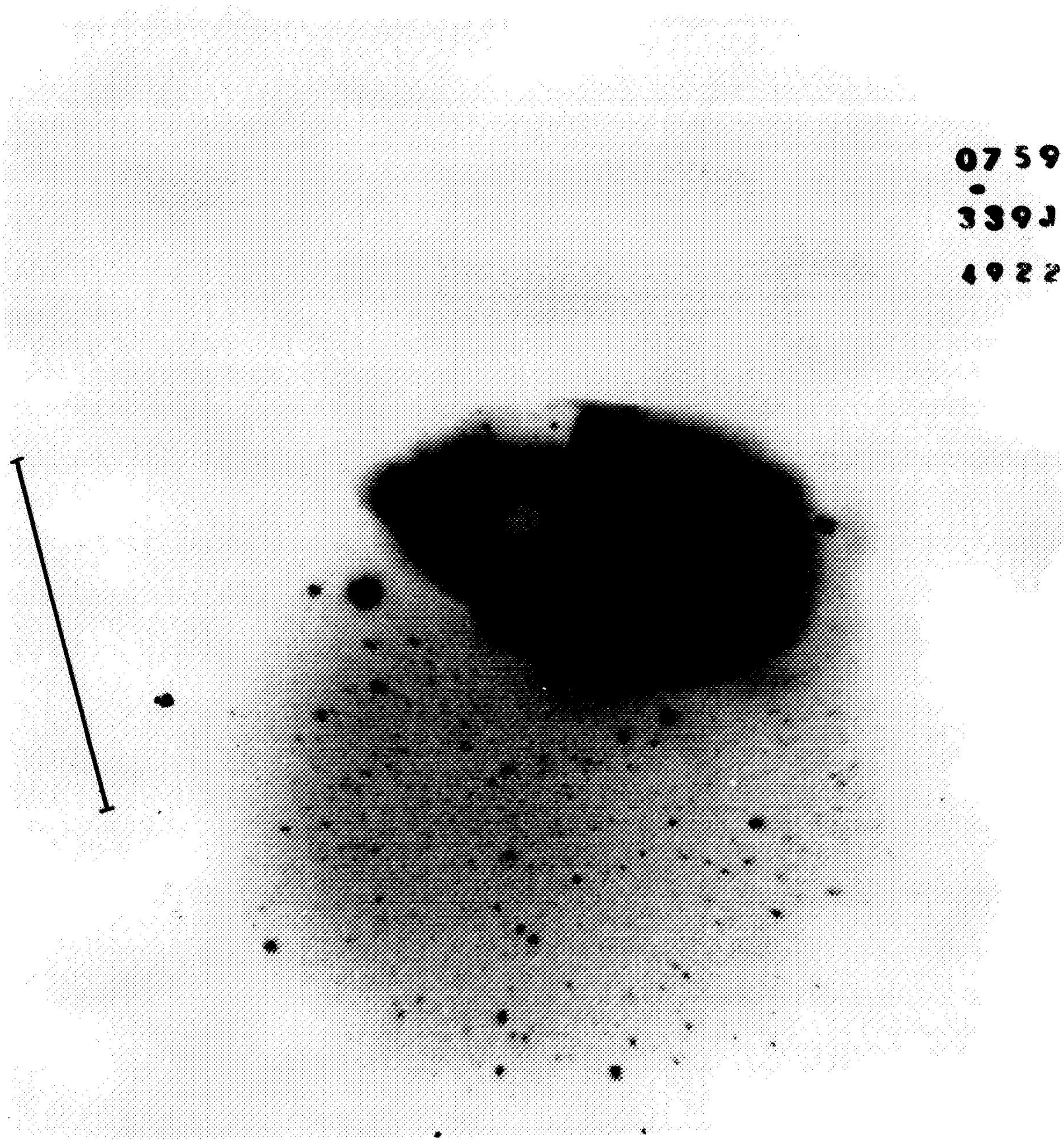

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FIGURE 3 PICTURE TAKEN DURING SECOND SIGNATURE PULSE. The line on the left-hand side is the calculated position of the auroral streak, which is clearly out of the field of view of the camera.