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High Speed Video Data Acquisition System (VDAS) Developed for H.E.P. Used to Study Comet Halley*

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HIGH SPEED VIDEO DATA ACQUISITION SYSTEM (VDAS) DEVELOPED FOR H.E.P. USED TO STUDY COMET HALLEY.

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Abstract

A high speed Video Data Acquisition System (VDAS) developed for high energy physics coupled with a telescope and image intensifiers was used to study comet Halley. The system is capable of producing and storing an image of the comet at standard video rates of 30 frames per second. The system was used to image fast variations in the coma and tail of the comet. Plumes of light were imaged which persisted for as little as 1/4 second, far to fast to be seen by conventional astronomical observation techniques. Fast time resolution spectral data were also taken using a 2.3 meter telescope. Preliminary results are reported.

Introduction

VDAS is a high speed digital image acquisition system developed for recording high energy physics active target events[1],[2]. VDAS was recently used to record short time resolution images of comet Halley. Astronomical observations of comet Halley or other astronomical objects are typically made with film or CCDs with exposure times measured in many minutes or even hours. VDAS, coupled with an image intensifier, is sensitive to the single photon level. This capability reduces the need for long image integration times and allows VDAS to record an image 30 times a second. This affords us a unique look at short term variations in intensity of the coma and tail of the comet which are hidden from conventional methods of astronomical observation.

VDAS Background

The high energy physics application for which VDAS was initially developed determined the system specifications. The system had to be very fast, able to digitize up to 30 million pixels per second. (The comet observations used standard video cameras and rates which where only about one fourth the maximum speed of VDAS). VDAS had to be triggerable, capable of asynchronously acquiring a single video frame. The system had to have the capacity to store a large number of images in order to accomodate high experimental trigger rates.

The requirement for storing a large number of images was met in two ways. First, VDAS includes an eight megabyte First-In-First-Out (FIFO) buffer memory capable of data rates of 30 megabytes/second. Second, to increase the effectiveness of this internal memory capacity, the system includes a hardware data compactor. The compactor reduces the number of bytes needed to store an image without losing image resolution. Details of these systems are discussed elsewhere[3].

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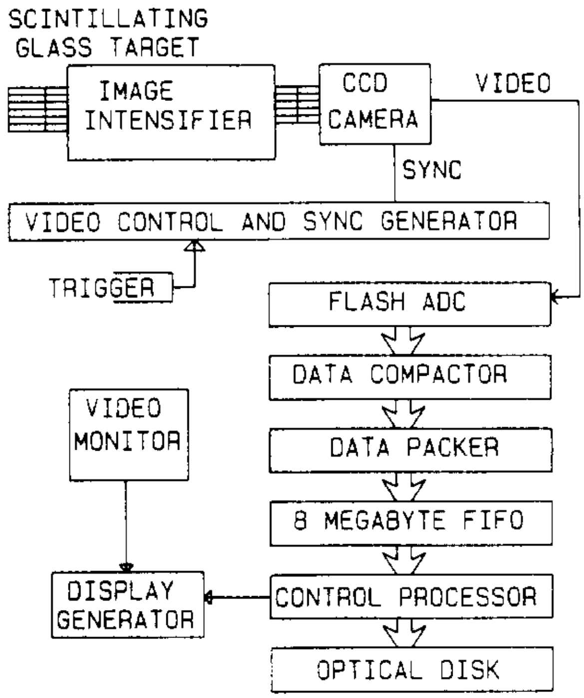

Figure 1. Overview of Video-Data-Acquisition system to be used in High Energy Physics for Fermilab Experiment E-687.

High Energy Physics and Comet Halley

High Energy Physics

The basic VDAS for HEP is shown in Figure 1. The video control and sync generator keeps the entire system synchronized to assure proper image alignment. The ADC converts the video signal to digital data with 6 bits of resolution. The data compactor removes pixel values below a digital threshold in a manner which allows the image to be precisely reconstructed. The data packer constructs a 32 bit word from the 8 bit data stream produced by the compactor. The FIFO acts as the image buffer, storing as many as several thousand compacted images.

Comet Halley

The prototype VDAS was being used for the evaluation of different scintillating glass targets using cosmic rays. These tests were being conducted at the University of Notre Dame. When the system was described to a curious astronomer, he realized that the system might be able to image comet Halley. As an experiment, the image intensifiers where placed at the focal plane of a small, 11 inch, telescope on the roof of the physics building.

The images of the comet produced in this first experiment were intriguing in that they were virtually could average up to 1024 frames, although we usually averaged no more than 16 frames (32 video fields). This gives an equivalent of a 1/2 second exposure of the comet, and is more than adequate to eliminate the noise component of the image and still produce images with a much shorter time base than typical astronomical observations.

HEP images are of charged particle tracks and the "grey" scales of the image are used to more accurately determine the centroid of the particle tracks. The images of the comet provide grey scale data which indicates the internal structure of the coma and/or tail. In order to more easily show these slight variations in light intensity, VDAS includes a provision for producing false or pseudo-color images of the comet. These pseudo-color images aid the eye in detecting details in the comet.

VDAS was capable of producing multiple high quality images of the comet every second, far faster then conventional astronomical measurements. In addition, a spectrometer was obtained which would allow real time spectral data to be recorded.

Observing site

The nature of the comet's orbit dictated that the team locate a southern hemisphere observation sight. The team was offered several sites both within and outside the of United States. The site chosen was the Siding Spring Observatory near Coonabarabran, New South Wales, Australia. The observatory agreed to provide lab space for VDAS and lodging for the team. The team brought its own 11 and 14 inch telescopes, as large telescope time is reserved well in advance.

Siding Spring is located about 700 km north west of Sydney, and sets atop an ancient volcano in the middle of a desert. The last rain at the observatory site had occurred over five months previously. The weather at the site varied from the 90s during the day to the low 40s at night with occasionally very high winds. Clouds or rain never prevented observing, however, on four nights the wind caused the telescopes to vibrate severely enough to make observations almost impossible.

The staff of the observatory was helpful in assembling the equipment but was curious about the amount. Most visiting observers would fly in for 3 or 4 days of observations and brought only changes of clothing. The imaging team, however, had arrived for a month and had brought almost a ton of equipment. The Australians were certain that they were dealing with a bunch of "crazy yankee physicists".

The comet imaging team spent a month in Australia from April 15 to March 12, 1986. In the first few days the team set up wind screens and was able to take data with both the 200 mm and 500 mm lenses as well as the 14" telescope. Once the astronomers at the observatory had a chance to see the results the team was able to obtain using the small telescopes, they arranged for the team to receive time on the new Australian National University 2.3 meter telescope. This instrument was still in the proccess of being commissioned and was not yet fully operational. The 2.3 meter ANU is an Alt-Azimuth telescope which is completely controlled by a VAX 780. The computer controls the guidance of the telescope, the rotation of the building, interior lighting and other operations. The system would occasionally crash and have to be rebooted, so the observatory provided the team with a licenced telescope "driver".

The usual cost for telescope time on a large instrument, such as the 2.3 meter, is about $1000 per half night. However, the observatory allowed the team 6 nights on this telescope. Using the 2.3 meter telescope the team was able to image the inner coma of the comet as well as perform real time spectral measurements. The images of the inner coma showed remarkable activity and dynamic changes from hour to hour and night to night. The imaging team was able to record very short term changes in the shape of plumes of light, as well as to observe "jets" presumably of gas emmitted by the comet.

Data Recording

The normal data acquisition mode was to record the live video on 2 VCRs, a 1/2" VHS HQ, and on 3/4" U-matic. The processed images were recorded on another 1/2" VHS machine. The total amount of data recorded was approximately 50 hours, representing over 5 million images of the comet. Selected images were digitally recorded on a streaming tape drive.

The processed video of the comet was made available to anyone who wanted it. Australian Television picked up the images and used them several times. The images were transmitted to the United States via satallite and were used several times.

Comet Halley data

The imaging team used a variety of optics to afford different views of the comet. Figure 3 shows in image of the comet using the 200mm lens and averaging 16 frames together. This is, in effect, a 1/2 second exposure of the comet and shows a prominent plasma tail extending toward the stars in the milkyway and a much fainter dust tail curving upward. The 200 mm lens with its 2.5 degree field of view gives a wide angle look at the comet. While this image is what most people expect a comet to look like, the best science is available at higher magnifications.

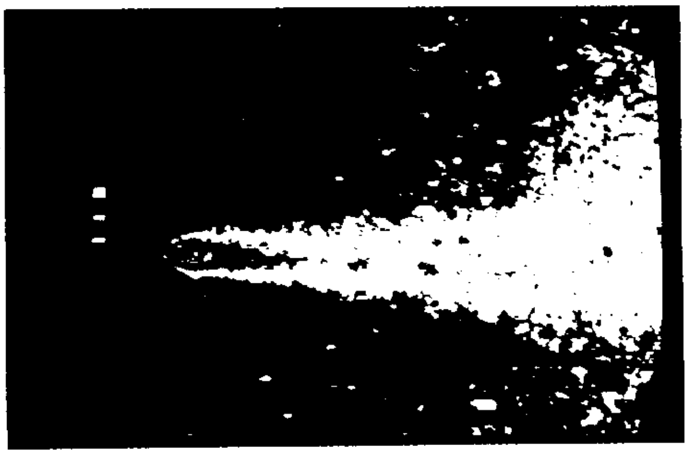

Figure 3. Comet Halley taken with a 200mm lens. This sixteen frame averaged image is equivalent to a 1/2 second exposure.

The 500 mm lens image, shown in Figure 4, covers a field of view 1 degree wide. The coma is much more visible and less of the tail of the comet can be seen.

The bulk of the data taken by the imaging team was with the 14 inch telescope. Figure 5 shows a typical view of the comet with the 14 inch. This telescope allows a view of about 10 minutes of arc which covers the coma fairly well. A very small indication of the tail can still be seen, however most of the interest is in the coma where the bow-shock is becoming visible.

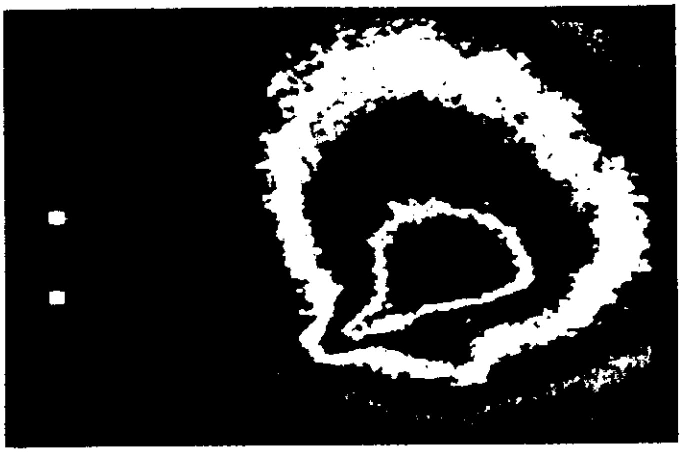

Figure 8. Comet Halley using the ANU 2.3 meter telescope taken on 3/25/86. The direction of the sun is towards the upper righthand corner of the image. This is a 16 frame average. Note the large plume or jet extending to the lower left.

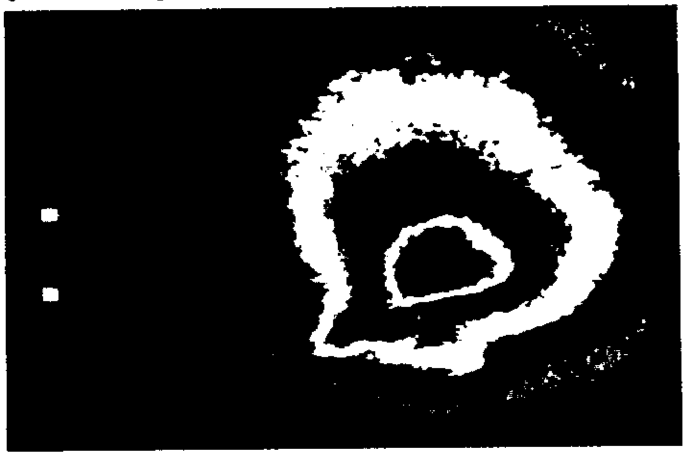

Figure 9. Comet Halley using the ANU 2.3 meter telescope taken on 3/25/86. The direction of the sun is towards the upper righthand corner of the image. This image was taken 2 hours later than Figure 8, note how the jet has changed and the inner coma is different.

only 40 seconds later. It shows at least 2 prominent plumes which appear as bulges in the contour plots. The team was able to image many such plumes with durations lasting from 1/4 second to several minutes. The very short, less than a minute, duration plumes are to fast to be caused by moving gasses or the solar wind. These are presumably some type of electrostatic discharge which occurs in the plasma of the comet. These discharges are still being studied.

Spectral Data

The 2.3 meter ANU telescope was used to take real time spectra of the comet as well as its surrounding coma and tail. Figure 11 is a section of spectra for the comet from 390 to 700 nanometers. While the analysis of the spectral data is in a preliminary state, it is believed that short term variations in the spectral ratios for several compounds have been recorded. Several compounds have been identified in the coma of the comet including; CN, CH, C2, C3, and NH2. Figure 12 and 13 show the same spectral region taken less than 1 minute apart. There is a change in shape of the spectra indicating that the ratios of the emitting compounds may have changed.

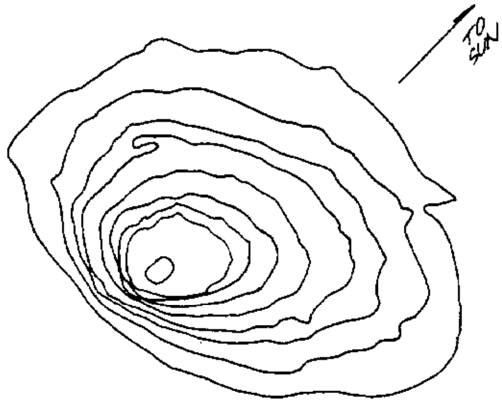

Figure 10a. This is a contour plot of the intensity levels of the comet taken on 3/24/86. Note how the contours are relatively smooth and there is little indication of activity.

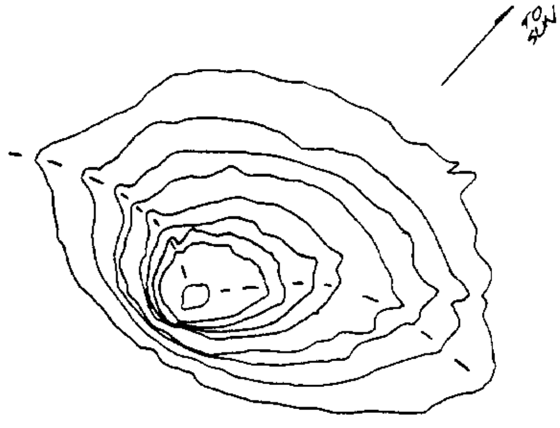

Figure 10b. This contour plot was taken 40 seconds later than the one in Figure 10a. Note the two plumes (dashed lines) which have developed.

Conclusions

Preliminary analysis of the data seems to show very short term fluctuations of order 1/4 second to perhaps 40 seconds, appear in the coma and near tail of the comet. These fluctuations are far to fast to be gasses or material moving in the solar wind and must be a discharge of some type in the plasma tail. Analysis of real-time spectral data taken on the 2.3 meter telescope has identified many compounds, and seems to reveal rapid fluctuations in the spectra. This may indicate an active chemistry in the comet and is being studied carefully.

VDAS has proved its capability to record astronomical data in a unique way. It is hoped that the data recorded has added to the understanding of the comet. The data will become part of the International Halley Watch Data Base and further results will be reported in astronomical journals.

in real time. The system was described to members of the astronomical community and those associated with the International Halley Watch. They were excited by the possibility of studing very fast changes which are expected to occur in the comet.

The system was able to produce live television images of the comet as a spinoff. These images, first produced in November of 1985, were given to the local television station and generated a great deal of interest both scientifically and for public relations purposes. The publicity associated with the live television images of the comet generated funding for an imaging test run in Florida during January. The imaging team would use the facilities at the U.S. Naval Observatory Time Service Station outside of Miami. Satallite companies provided uplink capability and the team was to transmit comet images free of charge to television stations across the United States. While the publicity generated the funding, the imaging team was most interested in the scientific data to be obtained. The Florida trip was viewed as an engineering run to determine if the system could produce valid scientific data and what, if any, changes to the system would be needed. To our knowledge, no other system could produce images of the comet at the standard rate of 30 frames/second. VDAS's speed would provide the opportunity to look for very fast changes in the structure of the comet.

__Image Differences: Comet Halley vs HEP__

Substantial differences exist between the images that the comet presented and the images the system was origanally designed to acquire. High energy interactions in scintillating glass targets produce images which exist only for a few microseconds, and consecutive images are quite different.

The use of an image intensifier with single photon sensitivity adds noise to the image. The noise is caused by thermal electrons on the photocathode of the image intensifier. This noise can be greatly reduced in the HEP applications by gating the intensifiers with an event trigger. The comet's image, however, is present all the time and gating would greatly reduce the intensity of the recorded images. The solution to this problem was image averaging which greatly increases the signal to noise ratio of the comet images.

The comet imaging team spent 2 weeks in Florida during January and was able to produce and transmit live and enhanced images of the comet to over 300 television stations in the United States and Europe.

The weather did not cooperate and the imaging team was able to record data on only 2 nights. However, the data from these nights demonstrated the scientific potential of the system. Preliminary data from Florida seemed to reveal a very active comet with flashes of light, or plumes, which persisted for only fractions of a second.

The success of this engineering run generated pressure from a variety of sources to image the comet using VDAS during March and April. The comet would then be at its brightest and most active state, having been heated by its close approach to the sun. Funding for this expedition was obtained primarily from the scientific community with some assistance from private corporations.

In preparation for the expedition, cometary experts were consulted as to the type of measurements that should be performed and which filters could be utilized to improve certain measurements [4],[5]. The team was able to make several changes to VDAS between January and March.

__VDAS Comet Configuration__

The basic system used to image the comet is shown in Figure 2. The image intensifier was placed at the primary focus of a telescope and its output was coupled to a Fairchild CCD camera with a fiber-optic input plate. The sync for the camera was provided by the VDAS sync board. The video signal was passed through a distribution amp and recorded on 2 VCRs while also being input to VDAS. The digitized images are stored in the FIFO. The hardware de-packer reads data from the FIFO and reconstructs the data stream, passing it to the image averager. The image averager adds successive images and performs a bit shift division. The averaged image is then written into the display generator which produces R-G-B video output based upon the stored image. The display generator uses look-up-tables to convert the black and white image into the false color image normally displayed.

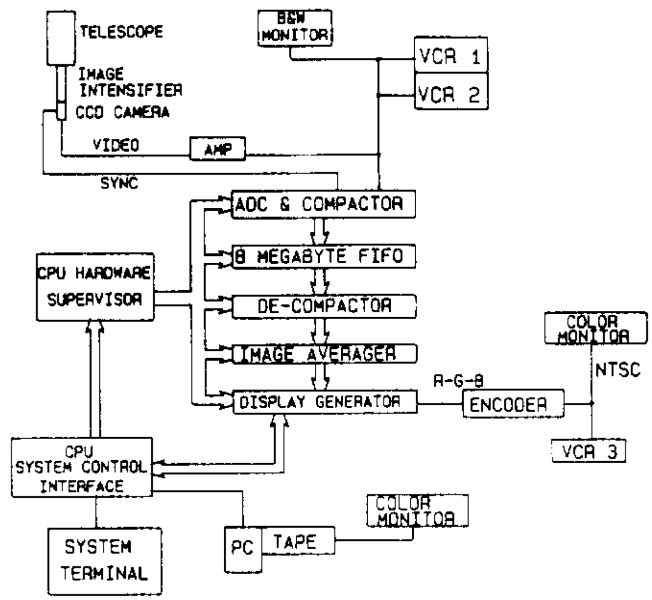

Figure 2. VDAS as configured for astronomical observations.

During the Florida expedition the data de-compaction, image averaging, and image reconstruction were all performed by the control CPU. While the data was interesting the speed of the system was not. The image averaging required by the comet data put an increased load on the system. The problem of image reconstruction speed was overcome by designing and building two modules, the hardware data de-compactor and image averager. Details of these are discussed elsewhere [6]. The modified VDAS also had a second processor added to increase speed by offloading the human interface and image enhancement tasks to another processor. The system control processor set parameters such as the number of frames to average, the digital threshold for compaction, and grey scale enhancements.

The original system took about 6 minutes to depack and average 30 frames, the new system took less than 20 seconds to do the same task, this is a factor of over 15 in reconstruction speed and was essential for an extended data taking run. The image averager

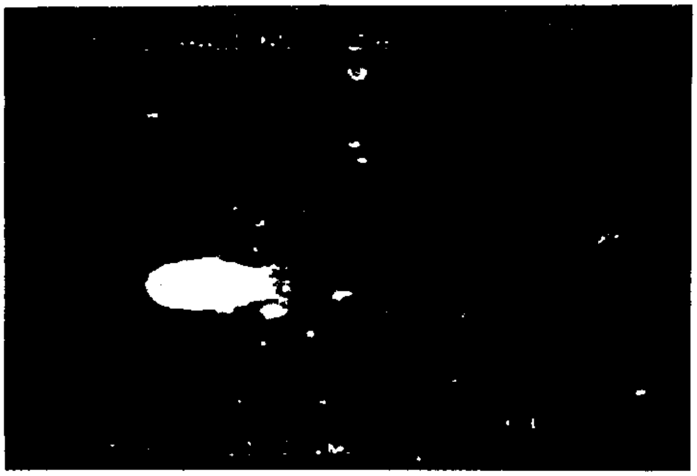

Figure 4. Sixteen frame average of the comet using a 500mm lens.

Figure 5. This is an eight frame average of the comet using a Celestron 14 inch telescope. Little of the tail is visible at this magnification.

__2.3 Meter ANU Telescope Images__

The two best images of the comet were probably the 200mm lens for seeing an object that "looks" like a comet and the 2.3 Meter ANU for a very detailed view of the inner coma of the comet. The 2.3 meter has a field of view of only 50 seconds of arc. The image shown in Figure 6 is from the 2.3 meter taken 3/23/86. This image is of an area only 2 pixels wide in the 200mm lens image. The comet is exhibiting a fan shaped bow-shock in the direction of the sun, which is toward the upper righthand corner, as material is heated and boils off on the sunward side of the comet.

Figure 7 is an image from the 2.3 meter taken on 3/24/86. The comet has changed drastically over the last 24 hours and has brightned somewhat. The fan shape is now much broader and the bow-shock is wider. This image shows one of the many plumes observed which will be described in detail later.

Perhaps the most dramatic change is found the next day as Figure 8 shows. This image is from 3/25/86 and shows a large jet of material which had developed in the direction opposite the sun. The jet changed and dissipated over the evening and the shape of the coma also varied. Figure 9 is an image taken about 2 hours later than the image in Figure 8. The

Figure 6. Comet Halley using the ANU 2.3 meter telescope taken on 3/23/86. The direction of the sun is towards the upper righthand corner of the image. This is a 16 frame average.

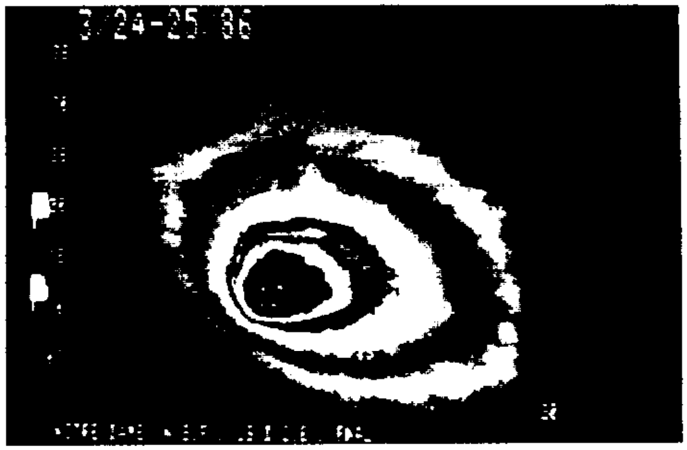

Figure 7. Comet Halley using the ANU 2.3 meter telescope taken on 3/24/86. The direction of the sun is towards the upper righthand corner of the image. This is a 16 frame average.

jet can be seen to be broader and less distinct. Both Figures show an apparent plume or bow-shock which seems to be associated with the jet and not the nucleus of the comet. This may be an indication that the jet was indeed a piece of the comet nucleus which had broken away and was acting as a second source of gasses. This may also explain why the comet had brightened substantially on this night.

__Results__

__Fast Fluctuations In The Comet__

One of the primary goals of the imaging team was to study fast fluctuations in the comet. These fast fluctuations are predicted to exist and should be an indication of the plasma nature of the coma and tail of the comet [4],[7]. It is these variations that VDAS has the unique capability to study. Data collected on these fluctuations would suppliment data gathered by the probes which flew by the comet and other ground based observations.

The imaging team found the comet to be incredibly active not only exhibiting long term changes as shown, but very fast changes as well. Figure 10a shows a contour plot of the comet taken 3/24 and has little evidence for plumes or bright areas radiating from the nucleus. Figure 10b is the same contour plot taken

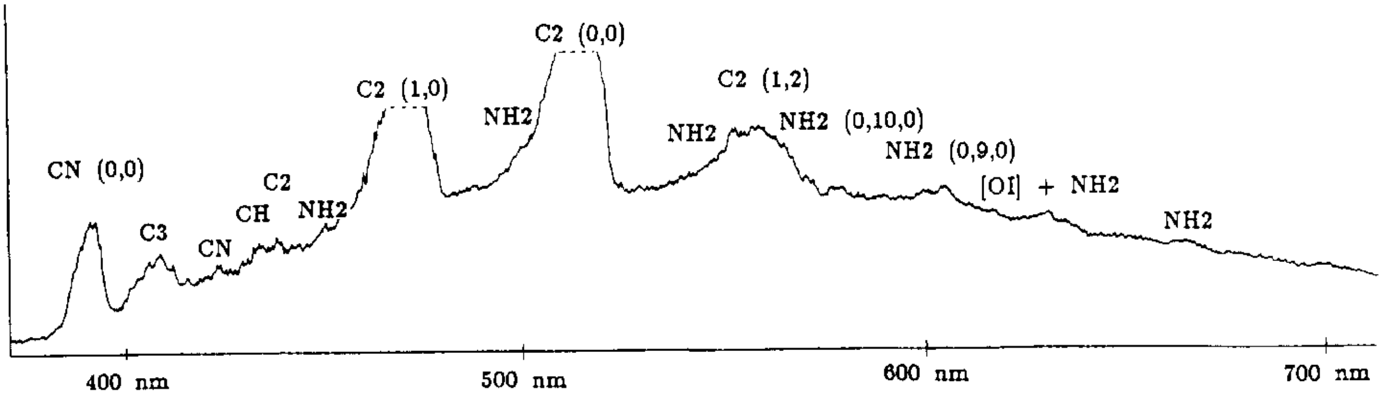

Figure 11. This is a section of the spectra of comet Halley taken 3/24/86. The region of the spectra covered is from 390 to 700 nanometers. The nature of the spectrometer only allowed a small region of the spectra to be taken at a time.

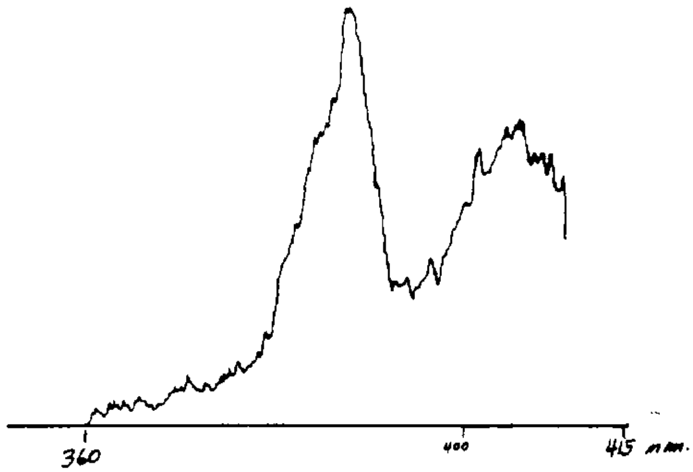

Figure 12. This is a plot of the spectra for a small section from 360 to 415 nanometers taken 3/24/86.

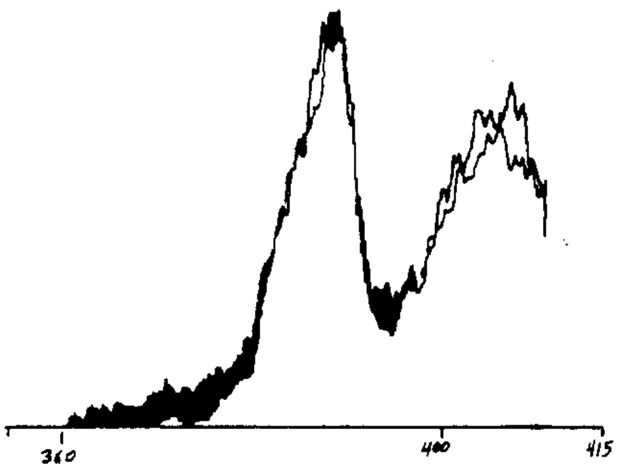

Figure 13. This is a plot of the same spectra as Figure 12 taken less than 1 minute later. The differences have been highlighted.

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-Australian Customs and Immigration for their help in expediting the clearance of our equipment.
-and United Airlines who flew 1700 pounds of equipment to Australia and back free of charge.

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