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# Visual Photometric Experiment: A Getaway Special Payload Aboard STS-042

Paul D. LeVan*
*U.S. Air Force Phillips Laboratory, Kirtland Air Force Base, New Mexico 87117-5776*

**Visible-light sensors were flown aboard the Space Shuttle in order to measure, without contamination by atmospheric airglow, the zodiacal light (sunlight reflected from interplanetary dust). A photomultiplier tube and four selectable optical filters constituted the primary sensor. This filter-wheel photometer was supplemented by two video cameras, which imaged star fields for aspect determination and provided an assessment of contaminating radiation. The suite of instruments was configured as part of a Getaway Special (GAS) experiment, in order to obtain the measurements at the lowest possible cost. As a GAS payload, the instruments were required to operate nearly autonomously. The payload had no gimbaled optics and no influence on the attitude timeline of the space shuttle. Only the enabling and disabling of data collection in accordance with prelaunch scheduling was controlled by the GAS payload specialist. Despite these limitations, the diffuse character of the zodiacal light permitted the serendipitous measurements described here. Several scans across the zodiacal dust plane were recorded, and provided peak brightness values for the zodiacal light at several solar elongation angles. A preliminary analysis of data redundantly recorded on a VHS audio track indicates ratios of zodiacal-light brightness in three spectral bands that are comparable to solar brightness ratios, confirming a result obtained previously with a balloon-based experiment.**

## Introduction: Zodiacal and Diffuse Galactic Background Light

THE celestial background consists of the pointlike distribution of stars, as well as extended radiation from dust particles in the plane of the solar system and dust particles in the interstellar medium. Sunlight reflected from dust in the solar system is called zodiacal light because, like the planets, it is confined to the constellations of the zodiac on the celestial sphere. Starlight reflected by the interstellar dust is called diffuse galactic background light (DGBL). The DGBL is concentrated along structures of the Milky Way, including local galactic structures such as the Orion Spur and the Perseus Arm.

The zodiacal light is sufficiently bright for viewing angles close to the sun to be visible near dusk and dawn from dark viewing sites. Nevertheless, it cannot be directly measured from ground sites without the measurement being contaminated by upper atmospheric airglow. The airglow, leading to the nonzero night-sky brightness level, arises from atmospheric layers nearly 100 km high. Rocket-borne, orbital, or interplanetary platforms are therefore needed to measure the zodiacal and diffuse galactic background light without airglow contamination. The Visible Photometric Experiment (VIPER) described here measured zodiacal light as a Getaway Special (GAS) payload aboard the space shuttle.

The Air Force and Department of Defense interest in backgrounds derives from their constraints on target detection. Bright backgrounds render a target at lower contrast. Furthermore, modern detectors operate at low system noise levels and can have their noise floor determined by random fluctuations in the photon rate from the background. Spectral bandpasses must be selected to maximize the ratio of target signal to background noise over the viewing angles of the particular application.

The inclination of the earth's orbit relative to the zodiacal plane suggests the occurrence of seasonal variations in zodiacal brightness. Therefore, archived data on zodiacal light may be combined with newer results to provide an improved understanding of variations with both viewing angle and time of year. Previous exoatmospheric measurements of the visible zodiacal light were made by the NASA Pioneer 10 and 11 interplanetary probes,[1] an Air Force earth-limb clutter experiment flown in 1983, and a University of Florida Space Shuttle experiment.[2] Reference 2 found the radiation levels associated with the orbiter itself to dominate the zodiacal light for viewing angles away from the zodiacal plane. For this reason, a large-viewing-angle, intensified video camera was chosen for VIPER to image orbiter-induced particulates and the structured backgrounds associated with either thruster firings or the shuttle glow phenomenon. The camera was boresighted to include the field of view of the primary instrument, a radiometer with selectable optical filters.

This paper reports on an analysis of data extracted from the VHS data recorder flown with VIPER. A complete picture of the mission awaits processing of data recorded by a digital recorder.

## VIPER Light Detectors

The primary instrument on VIPER is an integrated photoelectric sensor, which is an efficient light meter that operates over a broad range of brightness levels. This instrument consists of a photomultiplier tube and detection electronics that distinguish between signal and noise events, as shown in the Fig. 1 schematic. The device discriminates the pulse width of photoelectrons arising from a single photon against that of noise resulting from the thermionic emission of a single electron. The frequency of the output signal is proportional to the brightness level of light incident on the device. The VIPER photoelectric sensor is an EMR Photoelectric Model 541N-01-14. The output signal frequency is recorded on a VHS audio track, and is also converted to high and low voltage levels and then sampled prior to being digitally recorded.

The radiometer consists of the photoelectric sensor described above, and foreoptics comprising a five-position filter wheel and a 50-mm commercial camera lens, as shown in Fig. 2. The foreoptics is protected by a set of dark baffles from the light of bright sources outside a 1 deg circular cone. This protection permits the VIPER viewing angle to come within a 35 deg cone of the sun without the off-axis contribution interfering with measurement of the zodiacal light. The filter wheel rotates by discrete amounts, sequentially placing each spectral filter in the optical beam. As shown in Table 1, the range of wavelengths for these filters extends from the blue portion of the electromagnetic spectrum to the red, similar to that of the human eye. The dwell time in each filter is 6.4 s, and 2 s is spent between filters as a measure of the dark signal in the radiometer system. The dead time in moving between fixed positions is a little more than 2 s. The filter-wheel position, high- and low-gain

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*Astrophysicist, Backgrounds Branch, Geophysics Directorate.

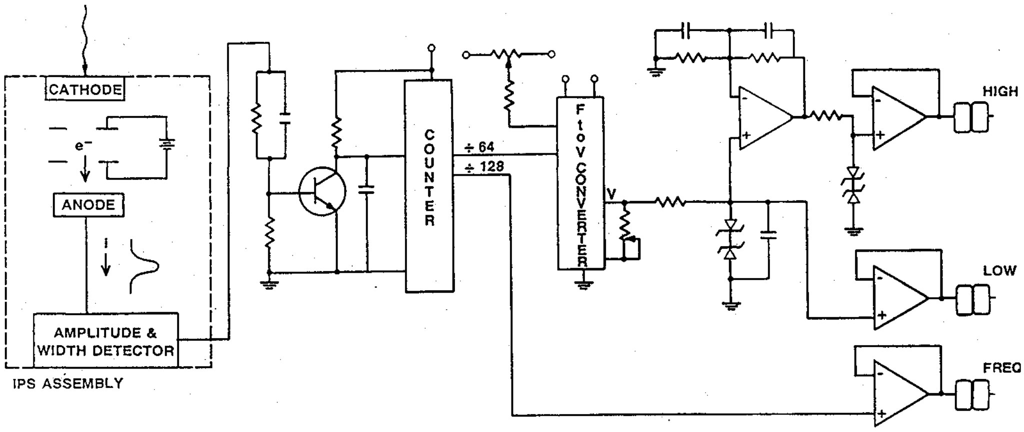


**Fig. 1 Radiometer electronics. The IPS output frequency is divided and conditioned (FREQ) for recording as VHS audio.**

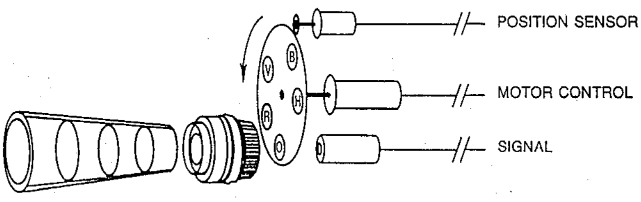


**Fig. 2 Radiometer optics. The rotating wheel selects individual filters (see Table 1 for filter key).**

radiometer signals, and all payload temperature and pressure monitors are encoded into frames of data that are written to a digital data recorder. The 4800-bit/s data rate samples the radiometer signal at 100 Hz, and the various other monitor voltages at 20 and 1 Hz.

## Star-Field Video and Radiometric Audio Recording

Two video cameras were employed to record star fields and shuttle particulates crossing the field of view of the radiometer. The relative fields of view of all three sensors are shown in Fig. 3. Knowledge of the attitude history is a key requirement for most space experiments. In the case of VIPER, the attitude history must be known to determine the viewing angle of the radiometer throughout the mission. Our determination of the attitude history is facilitated by the fixed alignment of VIPER in the Space Shuttle bay, since the attitude of the Space Shuttle is specified by NASA after a mission. The problem of attitude determination is therefore reduced to knowing the transformation from the Space Shuttle coordinate system (roll, pitch, and yaw) to the VIPER axes. This transformation is expressed mathematically as multiplication of a three-component unit vector by a $3 \times 3$ matrix. A star field observed with the video cameras at any time during the mission and identified with cataloged stars determines this transformation. The transformation can then be used with the shuttle attitude history to determine VIPER viewing angles over the entire mission.

The video signals from the two star-field cameras were multiplexed prior to being recorded on a VHS tape cassette. The multiplexing alternates the recorded video between the two cameras. The switching of the camera video occurs prior to each rotation of the radiometer filter wheel to the next filter position. If one of the cameras should fail, the odd number (five) of filter positions on the filter

**Table 1 VIPER optical filters**

| Sequence, s | Filter Name | Symbol | Half-power wavelengths, nm | |
|---|---|---|---|---|
| 2.2–8.4 | Blue | *B* | 391 | 489 |
| 15.0–21.4 | Hydrogen α | *H* | 656 | 657 |
| 27.8–34.2 | Open | *O* | 350[a] | 625[a] |
| 40.6–47.0 | Red | *R* | 590 | 810 |
| 53.4–59.8 | Visible | *V* | 506 | 595 |
| 64 (end) | | | | |

[a]Photomultiplier half-power wavelengths.

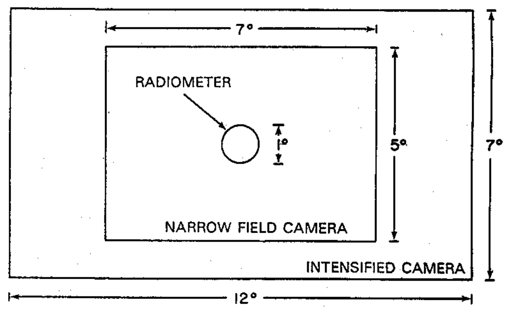


**Fig. 3 Fields of view of the radiometer and star-field cameras.**

wheel ensures that video over all filter positions will be recorded after two full rotations of the filter wheel. A code representing the payload controller clock time is inserted into the video stream. The "time code" consists of a 64-bit white-on-black display comprising a fixed, 16-bit synchronization pattern followed by six 8-bit groups representing month, day, hour, minute, second, and one-hundredth second. The video timecode allows star fields to be correlated in time with the radiometric data stored on a separate digital recorder. The offset of the video timecode relative to NASA MET can be determined with thruster firings, since the times for these are recorded by NASA, and the change in the motion of the star fields in the video is obvious.

The two audio channels of standard VHS were also used for data storage. Both the signal of the radiometer and a signal frequency proportional to the filter-wheel position are recorded as pure tones on the audio tracks of the VHS cassette. These signals can be recovered with high fidelity using a zero-crossing detector and electronic counter. Since both the radiometer signal and the filter-wheel position are also recorded on the digital data recorder, the VHS audio tracks provide redundant recording of these data.

## VIPER Autonomous Controller and Operating Modes

VIPER, as a celestial-background measurement experiment, has several operating constraints for data collection aboard the Space Shuttle. Many of these constraints must be accommodated autonomously, since the Getaway Special class of payload allows no prior specification of the Space Shuttle attitude timeline, and only minimal astronaut intervention. The three modes of VIPER—off, standby, and active data collection—are controlled by conditions both internal and external to the payload, and by the astronaut using the NASA *autonomous payload controller* (described under a separate heading below). The operating constraint of celestial viewing is accommodated by the astronaut, who follows a fixed timeline based on the planned attitudes of the orbiter and known well before launch. The astronaut disables active data collection for earth-viewing shuttle attitudes, or for long viewing periods of the same star field. Data collection is autonomously inhibited if VIPER is pointed too close

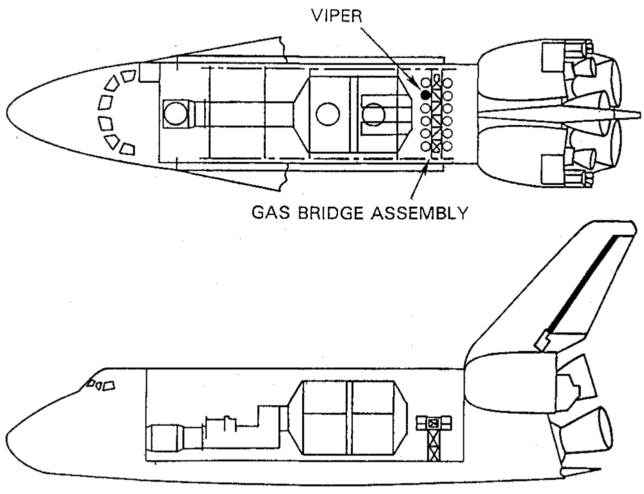


**Fig. 4 VIPER in Discovery, showing its location on the GAS bridge, and the bridge in the orbiter behind the International Microgravity Laboratory module.**

to the sun or moon. Dedicated photodiodes with light baffles defining a 35 deg cone are periodically checked for high signal levels. If the signal exceeds a threshold corresponding to that of crescent moon, a rotating shutter is closed to protect the light-sensitive instruments from damage. Temperature extremes inside the payload, or very low battery voltages, will also inhibit active data collection.

In active data collection mode, the radiometer signal, filter-wheel position, and housekeeping monitor voltages are digitally recorded. The star-field video and radiometer signal are written to a VHS data cassette. Only housekeeping data acquisition occurs when VIPER is in the standby mode, as light-sensitive instruments and data recorders are turned off for the conservation of payload power. In this mode, a 1-s data frame comprising voltage, temperatures, and pressures is recorded digitally every 22 min.

## VIPER Operations Aboard STS-042

The primary payload on STS-042 was the International Microgravity Laboratory, a pressurized crew module that occupied most of the shuttle bay. This mission also included the GAS bridge, a shuttle cross-bay structure with fixtures for 12 GAS canisters, which was mounted close to the aft bay wall as shown in Fig. 4. The orbiter used for STS-042 was Discovery (OV-103). Discovery was launched on January 22, 1992 at 14 h 52 min Greenwich Mean Time (GMT). The orbit was nearly circular (eccentricity 0.006), with period 90.4 min and inclination 57 deg. Orbiter motions were kept to a minimum in order to provide a benign environment for microgravity experimentation. The orbiter attitude was nearly tail-to-Earth. The orbiter pitch angle was within a few degrees of the plane of the orbit, but a more substantial roll angle relative to the plane partially exposed the orbiter underside to the negative velocity (RAM) vector, leading to viewing angles for VIPER that were offset from the orbital poles by similar angles. The need to minimize temperature variations over the orbiter exterior was met with two 180-deg rotations about the orbiter roll axis every 24 h. These 180-deg rolls had the effect of alternately facing the shuttle bay towards the northern and southern celestial hemispheres. In January, the southerly pointing resulted in appreciable warming of the orbiter bay and experiments.

## On-Orbit Operations

VIPER orbited with 11 other GAS canisters. A Space Shuttle crew member controlled all GAS experiments with the hand-held "autonomous payload controller." Here, pulse control modulation is used to encrypt commands, which are sent simultaneously to all payloads. The first command sent by the crew member is the unique code for each GAS experiment. Subsequent commands control the individual experiment addressed. VIPER was commanded in this way approximately 31 h into the mission. The command sequence first closed the internal battery circuit relay, and then caused a hinged cover over the top of the canister to pivot to the open position, placing it parallel to the aft wall of the International Microgravity Experiment (see Fig. 4). Within several seconds VIPER had uncovered its light detectors and begun acquiring data. Shortly afterwards, the space shuttle began a 180-deg rotation about its roll axis, of 22 min duration. With the tail of the shuttle pointing to earth during the rotation, VIPER, with viewing angle normal to the shuttle bay, slowly scanned celestial backgrounds close to the earth's horizon. VIPER was later placed in standby mode by the astronaut, using the hand-held controller. This action conserved VHS recording tape during repeated viewing over a circle circumpolar to the northern pole of the orbit. At 37 h into the mission, the shuttle was again rotated about its roll axis to equalize temperature, and active data collection was again enabled by the astronaut. Owing to cooperation of this type on the part of NASA, two long scans of the celestial sphere separated by 6 h were recorded on the 2-h 40-min VHS cassette. A summary of the VIPER timeline is listed in Table 2. The celestial coverage obtained over the mission is described in the Appendix.

**Table 2 VIPER (GAS-336) on-orbit operations[a]**

| Time: GMT, 23 days + | Time: MET, 1 day + | Event | Comments |
|---|---|---|---|
| $21^h53^m$ | $07^h00^m$ | Initial payload power | Enabled by astronaut |
| $21^h59^m$ | $07^h06^m$ | Orbiter begins 180-deg roll | 22 min duration |
| $22^h20^m$ | $07^h27^m$ | Inhibit data collection | Bright-light shutdown |
| $22^h21^m$ | $07^h28^m$ | End 180-deg roll | Northern Hemisphere |
| $22^h51^m$ | $07^h58^m$ | Initiate data collection | Background lights dim |
| $23^h51^m$ | $08^h58^m$ | Inhibit data collection | Bright-light shutdown |
| $24^h22^m$ | $09^h29^m$ | Initiate data collection | Background lights dim |
| $24^h23^m$ | $09^h30^m$ | Inhibit data collection | Shutdown by astronaut |
| $27^h23^m$ | $12^h30^m$ | Initiate data collection | Enabled by astronaut |
| $27^h32^m$ | $12^h39^m$ | Orbiter begins 180-deg roll | 21 min duration |
| $27^h53^m$ | $13^h00^m$ | End 180-deg roll | Southern hemisphere |
| $28^h03^m$ | $13^h10^m$ | Inhibit data collection | Autonomous shutdown |
| $28^h23^m$ | $13^h30^m$ | Inhibit data collection | Shutdown by astronaut |
| $44^h38^m$ | $29^h45^m$ | Payload power removed | Disabled by astronant |

[a]Launch of STS-042: Jan. 22, 1992, 07:53 CST.

## In-Flight Performance

The flight performance of a space experiment may differ from that determined from ground tests, owing to the effects of microgravity, temperature extremes, the vacuum of space, and cosmic-ray fluxes. Known variations can be accommodated by incorporating the results of ground tests taken over a range of the relevant parameter space. For example, the VIPER radiometer, whose photomultiplier tube has a response known to vary with temperature, was characterized over an extended temperature range. The only recourse against unknown effects is a comparison of the ground and space performance of component assemblies. The results of comparisons of this type for VIPER are described below.

## Performance of the Moving Mechanisms

Apart from the NASA GAS canister cover, which met all performance requirements, four mechanical systems on VIPER were required to operate during the mission. First, the sun shutter, which comprises a rotating disk with three identical apertures spaced at 120-deg intervals, rotates in steps of 60 deg. The sun shutter is open when the apertures are located above the three sensors, and closed when the sensors are blocked. Second, the radiometer filter wheel, also a rotating disk, has five filters spaced at 72-deg inter-

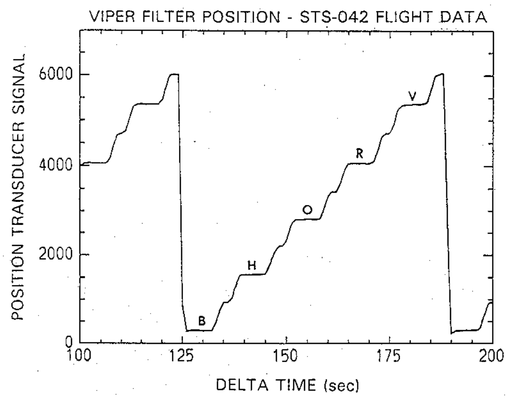


Fig. 5 **Recording of the filter-wheel motion during the STS-042 flight (see Table 1 for filter key).**

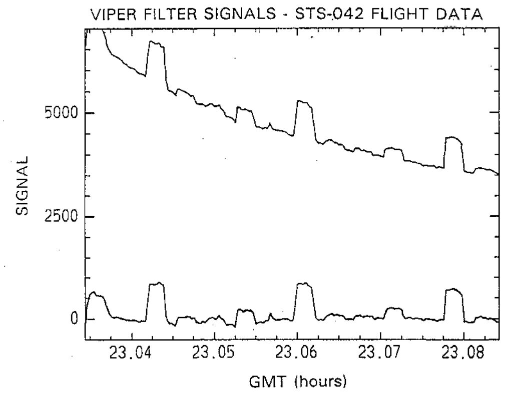


Fig. 6 **Signal levels before and after removal of the dark-current baseline, showing a decrease with time in the dark signal level.**

vals, and rotates in 36-deg steps during data acquisition. Third, the VHS recorder incorporates moving mechanisms identical to commercial units. Finally, the digital data recorder (Sundstrand Mark 48 Torpedo) has it own unique mechanism with details unknown to us.

The sun shutter opened and closed eight times during the mission: four times by command of the astronaut and four times due to dangerously high light levels, in the mode described previously. These events are clearly seen in the star-field video. The sun shutter was properly closed at the end of the STS-042 mission, and therefore behaved as required.

An evaluation of the performance of the filter-wheel mechanism includes a comparison of rotational speed measured on the ground and in space. A slowly running mechanism would exhibit less-steep transitions between the fixed positions and a reduction of time spent in each fixed position. The on-orbit motion of the filter wheel is shown in Fig. 5.

Judging by both the time interval for a full rotation and the sharpness of the transitions between fixed positions, the performance in space equaled that of the ground tests.

VHS recorders and cassettes are known to be adversely affected by extremes in temperature. Operation in microgravity may impose differing amounts of tension on the cassettes, and the launch vibrational levels affect tape slack in the rewound position. The space performance of the VHS recorder was gauged by the quality of the recorded video, and the video was found to be affected by the extreme conditions of space. Transcription of the flight video required both tracking and time-base corrections to achieve image quality comparable to ground performance. An improvement in image quality is noticeable during the first 30 min of the 2-h recording, and may correlate with the decrease in operating temperature over this time (the shuttle bay was moving away from the warm southerly orientation).

The digital recorder has a wider operating temperature range than the VHS unit. Subtle nuances in analog recording under adverse conditions are difficult to quantify, whereas digital recording is either successful or a failure. The digital recorder did not perform properly in space, as attempts to reproduce its data have been unsuccessful at the time this manuscript was prepared.

## Electrical Systems Performance

The "dark current" signal level of the radiometer is quantified in the blocked positions of the filter wheel between adjacent filters. The signals through each filter are superposed on the baseline of dark signal, as can be seen for the extreme case shown in the upper trace of Fig. 6. The baseline was observed to decay asymptotically from very high values at the beginning of each of three data acquisition sequences to benign levels. The initial high values exceeded the frequency recording limitations of VHS audio. Moreover, it seems likely from analysis of the data recorded on the VHS audio that the dark signal at its highest levels saturated the radiometer electronics between 31.06 and 31.40 h MET (21.94 and 22.28 h GMT). Examination of radiometer data recorded digitally will be necessary to confirm this conclusion. An accurate interpolation of the baseline under the filter signals must be subtracted in order to derive the true signal levels. An example of such a subtraction is shown in the lower trace of Fig. 6.

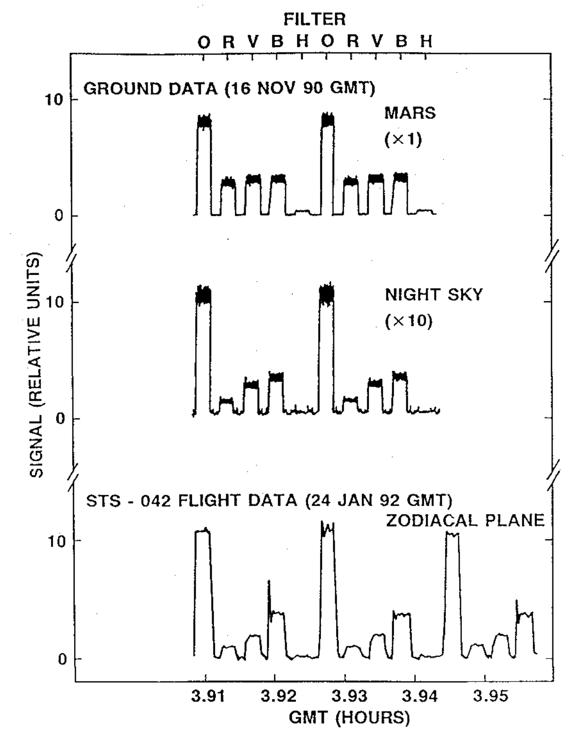


Fig. 7 **Comparison between ground-based signals of the planet Mars and in-flight signals of a zodiacal-plane crossing (see Table 1 for filter key).**

The signals from filter to filter are measured at 12.8-s intervals. Signals from the same filter are remeasured at 64-s intervals. The comparison of signal levels from different filters, at an identical time, requires interpolation of the signal levels to a common time. This can be visualized by fitting a line to three consecutive signal levels of each filter, as for example to those shown in the lower trace of Fig. 6. A determination of the ratio of signal levels for a filter pair is possible following this technique, and is employed for the analysis below.

## Transfer of Ground-Based Mars Calibration

VIPER was operated on the ground during the Mars opposition, when the planet is at its brightest, of mid-November of 1990. Multiple scans of Mars across the 1-deg radiometer field of view and at the earth rotation rate were recorded. These scans are shown in the upper two traces in Fig. 7, where it can be seen that the signal in the $O$ filter dominates, and that even the narrow-band $H$-filter signal is appreciable. (Figure 5 is useful in establishing the sequence of signals from the filters in Figs. 6–8, with the $O$ filter having the largest signal, followed by the $R$, $V$, and $B$ filters, and finally by the $H$ filter,

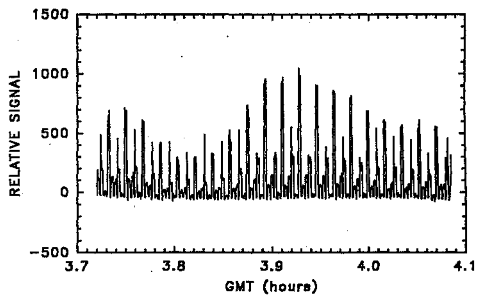


**Fig. 8 Scan of the zodiacal plane, with the asymmetry due to a change in orbiter motion at 3.88 h GMT.**

with the smallest signal due to its narrow width.) The primary utility of the scans was to map the radiometer field of view onto those of the video cameras. A secondary benefit is a ground-based calibration of the relative $B$, $V$, and $R$ filter photometry. The calibration is derived following the outline contained in Ref. 3. This calibration is an approximation in that it ignores color differences between our filter bands and those in the literature. The stellar magnitudes of Mars on November 16, 1990 for the three VIPER filters were estimated from the $V$ magnitude listed in the 1990 *Astronomical Almanac*[4] and published photometry,[5] and are $B = -0.6$, $V = -1.9$, and $R = -3.0$. For each of the three filters, we define a relation between stellar magnitude and signal level as follows:

$$X = -2.5 \log S_x - C_x \tag{1}$$

where $x$ (= $B$, $V$, or $R$) is the stellar magnitude corresponding to the sensor signal $S_x$. The constant $C_x$ is the logarithm of the zero-magnitude signal levels, and includes atmospheric extinction. We obtain $C_B = 3.7$, $C_V = 5.0$, and $C_R = 6.1$ for sensor signal levels expressed in units of 0.1 V. The resulting relative calibration is independent of the units of sensor signal level:

$$B - V = -2.5 \log(S_B/S_V) + 1.3 \tag{2a}$$

$$V - R = -2.5 \log(S_V/S_R) + 1.1 \tag{2b}$$

This ground-based calibration cannot be applied to the flight data, because the atmosphere attenuates the ground-based signals of each filter by different amounts. An estimate from observatory extinction curves of the differential attenuation by the atmosphere, for an elevation angle of 55 deg, is −0.1 for both 2.5 $\log(S_B/S_V)$ and 2.5 $\log(S_V/S_R)$. That is, 2.5 $\log(I_B/I_V)$ = 2.5 $\log(S_B/S_V) + 0.1$, where $I_x$ would be the signal level with no atmospheric attenuation. For signals measured exoatmospherically, Eqs. (2) become

$$B - V = -2.5 \log(I_B/I_V) + 1.4 \tag{3a}$$

$$V - R = -2.5 \log(I_V/I_R) + 1.2 \tag{3b}$$

One further consideration is needed before adopting the corrected ground-based calibration for use with flight data. The signals from Mars in the open filter are at the level of saturation. This is seen in Fig. 7 by the fact that the sum of the $B$, $V$, and $R$ filter signals exceed the $O$ filter signal. However, the $B$, $V$, and $R$ signal levels fall within a narrow range where nonlinearity effects would have little effect on the signal ratios. The calibration derived above is therefore applicable. (A rigorous demonstration of linearity for the limited range of signal levels recorded as frequencies on the VHS audio channel is shown in Fig. 5. A linear fit of signal frequencies to the fractional increments of filter-wheel position yields up to 6000 Hz.)

## Zodiacal Light Measures

Several crossings of the zodiacal dust plane resulted from the flight attitudes of STS-042 and the VIPER data collection sequences, as shown in the Appendix. As can be seen in Fig. 8, the signature of one of these crossings is pronounced even in the raw data, as

**Fig. 9 Star fields recorded on VHS video, with circles indicating moving particulates.**

is the signal from the galactic plane near 3.73 h GMT. (The peaks visible at the leading edge of the $B$ filter are internal light pulses used to monitor the radiometer's responsivity.) An unknown signal arising from diffuse shuttle contamination radiation may be present, but is at a level lower than the zodiacal-dust-plane profile at ±10 deg of peak radiation. Brightness ratios derived from the zodiacal signal levels can be expressed as color indices in stellar magnitudes, and compared with known color indices of stars. We follow the procedure outlined in a previous section to determine instantaneous signal ratios from the sequential filter measurements. The signal ratios are then converted into the color indices $B - V$ and $V - R$ using the exoatmospheric calibration of Eqs. (3). Signal-level ratios interpolated from the zodiacal-dust-plane crossing shown at 37.05 h MET (3.93 h GMT) in Fig. 7, with the dark-current baseline subtracted, are $I_B/I_V = 2.0 \pm 0.1$ and $I_V/I_R = 2.0 \pm 0.2$. The corresponding color indices are $0.6 < B - V < 0.7$ and $0.3 < V - R < 0.6$. The solar elongation angle for this scan is approximately 43 deg. The comparison of these values with the solar values, $B - V = 0.65$ and $V - R = 0.52$, confirms that the zodiacal-dust grains reflect sunlight with efficiencies that vary little over this wavelength range, as has been noted previously.[6]

## Backgrounds Associated with the Space Shuttle Environment

Two types of radiation associated with shuttle contaminants are evident in the video obtained with the VIPER cameras. One type results from sunlight reflected from particles that are seen to drift through the cameras' fields of view. Although these particles are difficult to distinguish from stars in Fig. 9, the distinction is easy while viewing the motions of stars and particles on the video. The particle density peaks within several minutes of a shuttle thruster firing (e.g., one used to execute the 180-deg Shuttle rolls required for temperature regulation). The radiometer signal from a particle saturates over the short time (< 1 s) during which the particle typically traverses the 1-deg field of view. The second type of contaminating radiation appears as a diffuse source that is brightest along one side of the camera field, with a brightness that declines toward the field center (Fig. 10). The peak brightness of this source tended to occur both before and after data collection was inhibited by the VIPER sun sensor (but not because of the sun's presence in its 35-deg field of view). The brightness of this source of contamination over the sun-sensor field of view is therefore comparable to that of the crescent moon. The radiometer signal level correlates with the brightness of the diffuse contaminating radiation seen in the video. The ratio of signals in the red and visible filters is similar to that for the zodiacal light, and therefore to the solar ratio, but the signal in the blue filter relative to the visible may be enhanced. Since the diffuse contamination source remains relatively fixed in the camera field, changing only in brightness, it may arise from the reflection of either sunlight or orbiter lighting onto the sensors, but determining the exact cause will require further analysis.

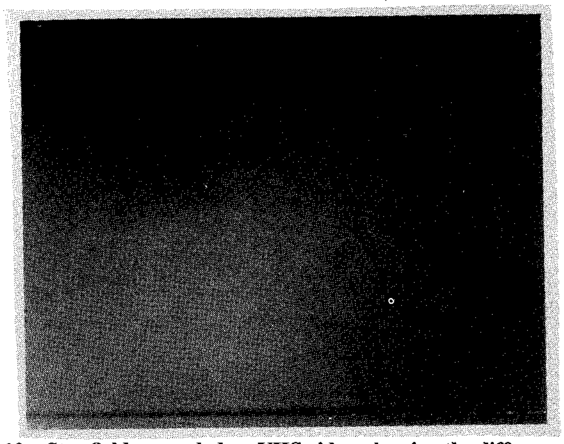

**Fig. 10 Star fields recorded on VHS video, showing the diffuse source of radiation.**

## Conclusions

This paper reports on the initial examination of data collected by VIPER during the STS-042 mission. After determining the VIPER operating sequences and concurrent shuttle attitudes, and analyzing selected data sets, it is concluded that VIPER collected zodiacal-light data from space, above the contaminating effects of atmospheric airglow. VIPER performed as well in space as during ground testing, with the exception of poor performance on the part of a commercial digital data recorder. It is shown that the flight data can be meaningfully interpreted and, in particular, that the measured signal ratios from the zodiacal light can be quantitatively compared with the known colors of the sun.

## Appendix: VIPER Data-Collection Pointing Aspect

The figures in this Appendix (Fig. A1) are adapted from NASA star charts for the STS-042 mission. The pointing shown is for the shuttle yaw axis, and does not incorporate misalignments between this axis and the VIPER optical axis. The purpose of these figures is to illustrate the approximate pointing over times during which VIPER was actively acquiring data. All figures are in coordinates of right ascension and declination (epoch 1992). The approximate pointing is shown by solid lines with time ticks at the endpoints. The zodiacal plane is shown by a solid line with tick marks corresponding to solar elongation angle. The time ticks on the pointing can be transformed to GMT with the relation GMT = MET + $22^d 14^h 52^m 33^s$.

## Acknowledgments

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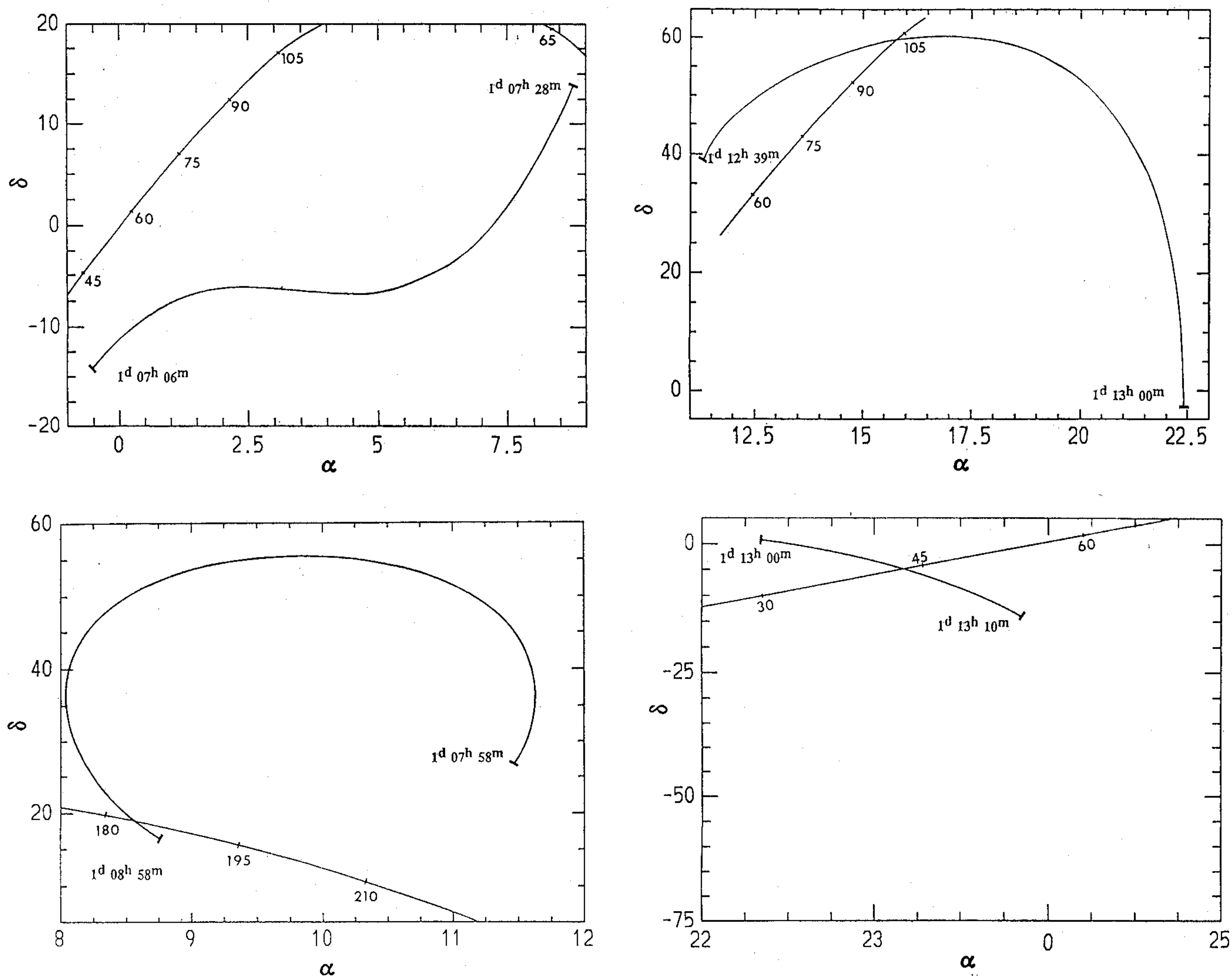


**Fig. A1 Approximate sensor pointing (with start and stop times in MET) and zodiacal plane (with solar elongation in degrees) plotted in celestial coordinates.**

with NASA personnel (Tom Dixon and co-workers)—integrated VIPER into Discovery. Systems Integration Engineering personnel (Chris Robinson and John Greco) delivered the final version of the safety documentation to NASA. Paul Cucchiaro (now of Sensor Systems Group, Waltham, MA) and Thomas Murdock (now of General Research Corporation, Danvers, MA) were two of the original driving forces behind the experiment. Andrew Mazzella and Kevin Larson of RDP, Waltham, MA, did the experiment planning and aspects of the data reduction. Stephan Price, as chief of the Celestial Backgrounds Branch, and Russ Steeves, as chief of the Space Experiments' Development and Verification Branch, supported VIPER over several years of its development. The Space Test and Transportation Programs Office of Air Force Space and Missiles Systems Center provided launch support and acted as liaison to NASA in obtaining approval for a VIPER shuttle flight.

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