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A New Look at the Evidence Supporting a Prosaic Explanation of the STS-48 "UFO" Video

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It has been argued that the seemingly unusual behavior of objects observed during the STS-48 space shuttle mission can be explained as the reaction of small debris particles floating near the shuttle to the firing of the spacecraft's rockets. Two independent lines of evidence are presented here that suggest there could have been no causal link between the objects' behavior and the rocket firing. The issue of the exact time of the events relative to the documented time of the rocket firing is first examined on the basis of times computed for horizon transits by stars during the shuttle orbit on which the events occurred. A significant discrepancy between the times displayed on the video recording and the times of expected horizon transits is described. The nature of the light flash itself is then examined in more detail, revealing that it was a sudden increase in the intensity of reflected light and could not have been the light emitted by burning rocket exhaust entering the camera's field of view.

Introduction

On September 15, 1991 during Flight STS-48, a camera in the payload bay of the Space Shuttle Discovery took a video sequence showing objects that seemed to behave in a highly unusual manner, at least to many people not intimately involved with space shuttle operations. The video was taken while the camera was recording lightning storms on the night-side of the Earth over the Indian Ocean and Southeast Asia.

The objects begin appearing near sunrise against the background of the Earth at different locations, moving in various directions. A little over a minute after the first object appears, a flash of light can be seen, and many -- but not all -- of the objects seem to respond to it by moving in roughly the same direction: towards the upper right hand corner of the field of view. The angular sizes of all of the objects are at or below the camera's resolution, so there is no way to directly determine their true size, form, speed, or distance from the camera.

Two investigators, Mark J. Carlotto [i] and Jack Kasher [ii], suggested that the objects are large and at a great distance from the shuttle, primarily on the basis of their seemingly anomalous behavior. Perhaps the strongest evidence in favor of this argument are the curved paths on which some of the objects travel as demonstrated by Carlotto, suggesting some of them were on trajectories following the curvature of the Earth.

Others, including SPSR members Vince DiPietro and Tom Van Flandern, argued that the objects were debris particles originating from the space shuttle itself and that they were relatively close to it when the imaged events occurred. However, it was James Oberg, former shuttle flight control officer and NASA contractor employee, who developed the most detailed and perhaps compelling case for the debris hypothesis[iii].

DiPietro noted that debris near the shuttle, previously invisible in the darkness of orbital night, would suddenly become visible at orbital sunrise. Oberg further observed that drifting shuttle debris emerging from the spacecraft's shadow could seem to appear from nowhere when suddenly illuminated by sunlight. This could explain why several of the objects in the video seem to originate from near the Earth's surface at the center of the image rather than drifting into the scene from the edge of the field of view.

What Oberg considers to be the strongest evidence for the debris hypothesis comes from one version of the video he acquired from NASA that displayed the video camera clock time. It showed that the flash of light to which the objects seemed to respond occurred within two seconds of the documented firing of a small vernier attitude control rocket in the aft end of the shuttle. The thruster is designated L5D, and was on the same side of the spacecraft as the camera. The "twin" R5D thruster on the opposite side of the spacecraft fired at the same time.

Oberg argues that the coincidence is sufficiently close to establish a causal relationship between the rocket firing and the movement of the objects; only small debris close to the spacecraft could be affected by the rocket exhaust. The time display also showed that the objects begin appearing very close to an orbital sunrise computed from the shuttle orbital parameters. Oberg argues that these two coincidences provide overwhelming evidence -- "proof" -- for the prosaic nature of the objects.

Clearly, proponents of the hypothesis that the video shows large, anomalous objects at a great distance from the shuttle should not ignore the apparently compelling coincidences Oberg noted. It is the purpose of this article to examine the evidence for those coincidences.

The Evidence for a Prosaic Explanation

In 1999, this author also acquired a copy of the "time-tagged" NASA STS-48 video at Oberg's suggestion. Curiously, the video contained not one, but two time displays that differed from each other by about two seconds as shown in Figure 1.

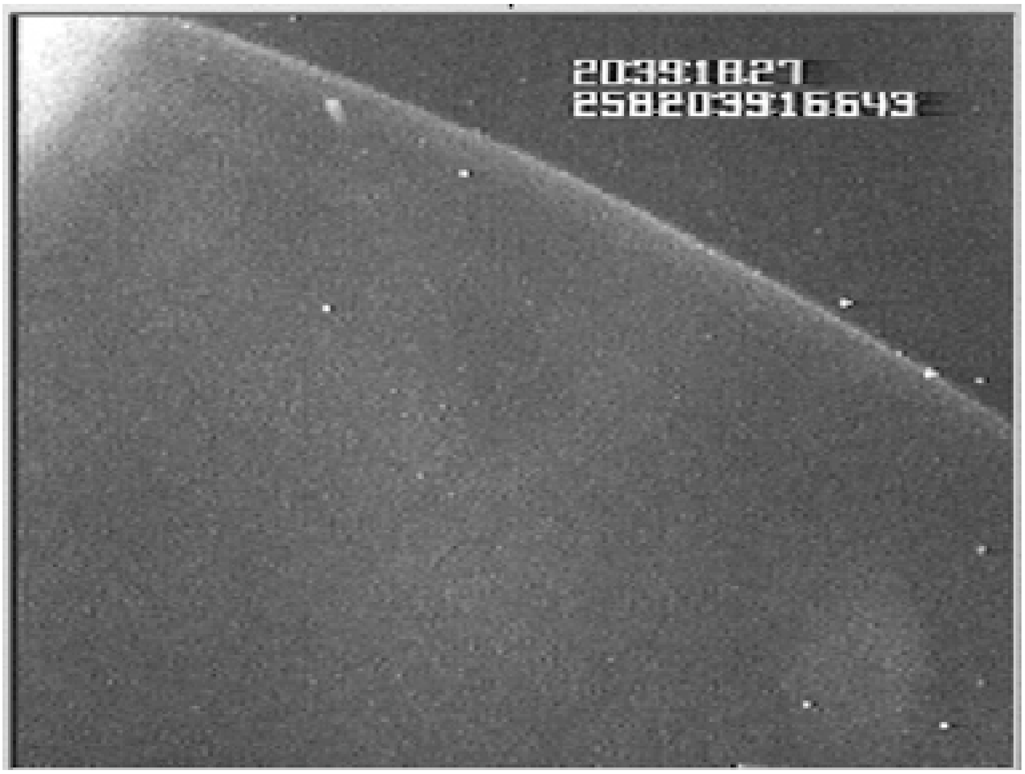

Figure 1 Sample frame captured from NASA video showing dual time stamp. Stars and several of the possibly anomalous objects are also visible.

On running the video frame by frame, the times (UT) were noted for the two events that are the basis of Oberg's argument. They are listed below for both time displays with the corresponding routine shuttle events to which they appear to coincide.

Event 1: The first object (designated M0 by Carlotto) appears.		Event 2: Flash of light	
Upper clock	20:38:08.833	Upper clock	20:39:24.600
Lower clock	20:38:06.573	Lower clock	20:39:22.349
Orbital sunrise	20:38:02	L5D thruster fires	20:39:23.79

Event 1, the appearance of object M0, seems to have a weaker causal link to a prosaic event than does Event 2. Orbital sunrise is a process that takes about 15 seconds between the times the upper and lower edges of the solar disk reach the horizon. The time of orbital sunrise was computed by Dan Adamo, NASA orbital mechanics expert and the Trajectory Officer in Mission Control at the time the video was taken. It is not known what definition of sunrise Adamo used. However, two authors of satellite tracking programs that the author has contacted both stated that they used the “astronomical” definition of sunrise to calculate the times at which a satellite is first illuminated by the sun during the course of an orbit. It is likely that Adamo did the same. The astronomical sunrise occurs when the center of the sun crosses the horizon.

It is unclear why objects should have suddenly emerged from the darkness of orbital night at a time when about 50% of the sun's disk may have already been visible. It might be that corrections of a few seconds to small errors in clock time or in orbital calculations would put the appearance of Object M0 closer to the onset of sunrise when the upper edge of the solar disk first cleared the horizon and the illumination intensity suddenly increased at the shuttle's position. The evidence presented for this scenario is not very strong, however.

It is the coincidence of Event 2, the flash of light, with the firing of the L5D vernier thruster that appears to be the more compelling evidence of a causal link to a routine shuttle flight event. The upper clock display indicates that the flash occurred 0.8 seconds after the thruster commenced firing, putting the event within the very brief span of time (1.2 seconds) in which the thruster was active. According to Oberg, a momentary imbalance in the oxidizer and propellant mixture could have briefly caused the otherwise invisible rocket exhaust to appear as a flame visible to the video camera when the exhaust gases entered its field of view.

However, it is only the upper clock that supports a causal link; if the reading of the lower clock display were to be believed, the light flash occurred 1.4 seconds before the rocket began firing, which would rule out a causal link altogether. But the upper clock display appears to be the original time record of the video camera itself. It is in the upper corner of the image, obscuring less of the image area. Its time format suggests that it was the camera's frame counter for a standard video format of 30 frames per second: the seconds counter is incremented once for every 30 increments of the fractional field. The reason for the existence of the lower time display is unclear, but it will be ignored because it does not support the prosaic explanation. Subsequently, all time references will therefore be to the original upper time display of the video camera.

The Timing Question: Is the Answer in the Stars?

Oberg's case appears undeniably strong, but it is completely dependent on how accurately NASA personnel set the video camera's clock. To date, there has been nothing offered to verify this clock's accuracy. The presence of a second -- and different -- time display on the official video lessens confidence in its accuracy rather than reinforcing it. However, there is a way to independently verify the accuracy of the time display: Given the state vector (also called "orbital elements") that describe a spacecraft's orbit and the appropriate software, the times at which stars cross the horizon as viewed from the spacecraft can be computed. The video clock times at which stars identified in the video sequence disappear near the horizon can then be checked against the computed times of their horizon transits.

When Oberg presented his case in 1999, he provided the two-line orbital elements (TLE) computed by Adamo (see Appendix) for his determination of sunrise. The TLE is a data format for orbital parameters used by NASA and NORAD. The author made a preliminary attempt at this verification procedure by entering Adamo's TLE data for STS-48 into the

Starry Night planetarium program[iv]. Among Starry Night's capabilities is the graphical display of the sky as it appears from the vantagepoint of an orbiting spacecraft.

Running the Starry Night display for STS-48 around the time of the appearance of the objects in the video, it was possible to identify numerous stars conclusively -- including the North Star (Polaris), which was among several stars previously identified by Carlotto. This experiment revealed a discrepancy between the time displays of the NASA video and Starry Night for the setting of every star checked. This discrepancy is illustrated in Figure 2, which shows a video frame at an instant in time just before the star Kappa Cephei sets and a similar frame from Starry Night. According to the video time display, the star disappears 16 seconds before the time of the horizon transit predicted by Starry Night. The time difference was about the same for all other stars checked.

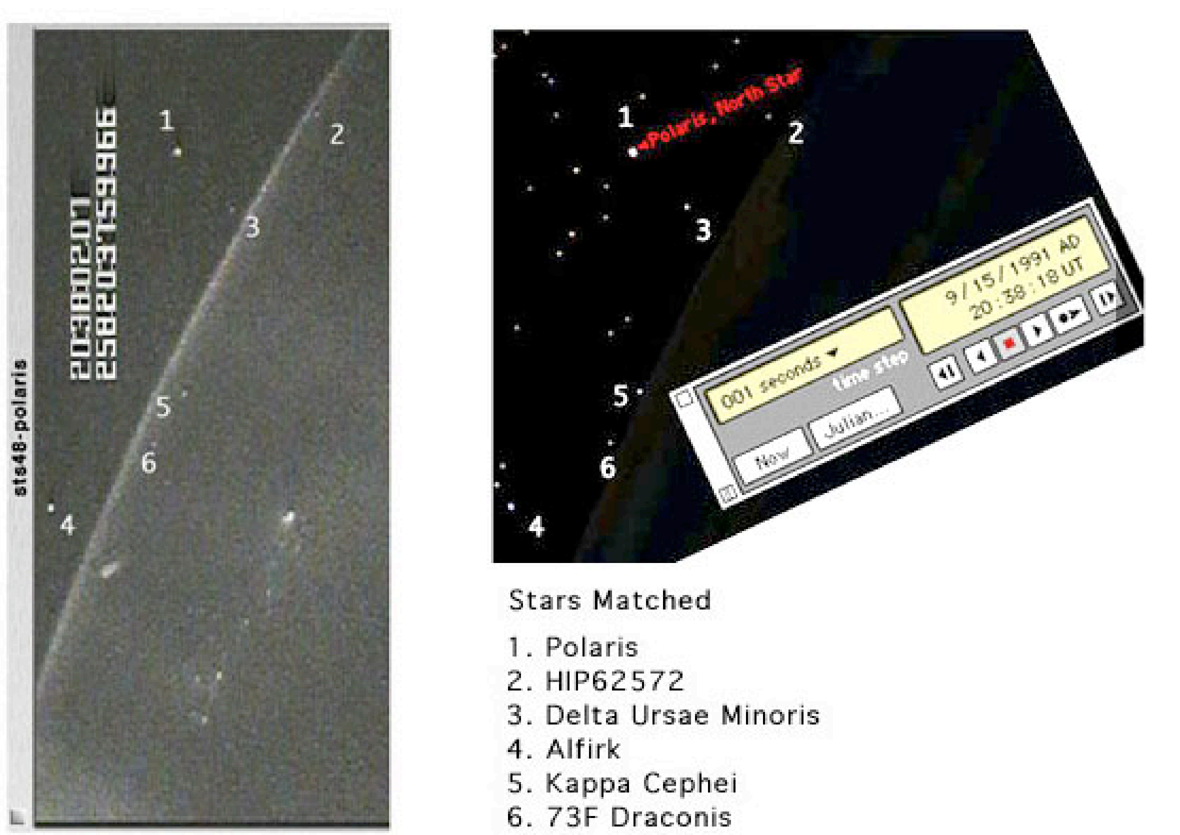

Figure 2. Comparison of an STS-48 video frame just prior to the setting of the star Kappa Cephei with the Starry Night display for the same event. The numbering indicates the corresponding stars.

If Adamo's TLE data and the Starry Night computations were accurate and the video time display were in error, then the light flash would have occurred almost 15 seconds after the L5D thruster had ceased firing. This would be far too long a time delay for any causal link to have existed between the two events.

But the Starry Night results were far from confirmation that the NASA video time displays were inaccurate; to the contrary, they raised three more questions:

- How accurate are the Starry Night computations? Starry Night is, after all, primarily a planetarium program to assist in viewing stars as they appear from Earth, not from satellites.
- How accurate are the STS-48 orbital elements provided by Adamo?
- Are the times at which stars appear to set in the video the times at which they actually set? Appearances may be misleading, and a star might be obscured by the Earth's atmosphere before the true setting time as it would be observed were the Earth an airless planet, perhaps explaining the apparently too-early setting times in the video.

These questions are addressed subsequently.

Accuracy of Predicted Times for the Settings of Stars

Developing a method to accurately compute the setting times of stars viewed from the vantagepoint of STS-48 was by far the most time-consuming and difficult verification task. The author contacted a Starry Night programmer and was advised that there were sacrifices in accuracy that had to be made for the sake of computational speed because the main purpose of Starry Night is to drive a real-time graphical display of the sky as viewed from Earth. He stated that errors in time computations were on the order of 5 seconds. This margin of error is too close to the size of the time differences between the disappearance of stars in the NASA video and horizon transits predicted by Starry Night to be confident that the difference is not entirely attributable to the error margin.

The Starry Night programmer suggested that the online satellite-tracking program Heavens-Above[v] would likely be more accurate because its purpose is to provide data on the times at which Earth satellites are visible from the ground and it is not constrained by any requirement for real-time simulation.

However, Heavens-Above gives no information on what the sky looks like from orbiting satellites with one exception: Heavens-Above reports the times at which a spacecraft leaves or enters the Earth's shadow and those times are equivalent to the rising and setting times of the sun as viewed from the spacecraft. That information, of course, is provided only for the benefit of those on the ground who want to know when a satellite is visible.

Another problem with Heavens-Above for the purposes of this study is that it reports only on satellites currently orbiting the Earth and can provide no information at all on STS-48, a mission that ended twelve years ago. But other "shareware" applications have been found online that bridge the gap between the capabilities of Heavens-Above and Starry Night.

A shareware application called Orbitrack[vi] was located that will generate a report on the rising and setting times of the sun for past spacecraft missions given the orbital elements. To verify the accuracy of this software, the satellite visibility data for two currently orbiting spacecraft was compared between Orbitrack and Heavens-Above. In the time periods examined, both applications reported the Hubble Space Telescope and the International Space Station leaving the Earth's shadow at exactly the same time to the second. Further, an Orbitrack report generated from Adamo's TLE for STS-48 at the time of the video event showed an orbital sunrise at 20:38:03, only one second later than the sunrise time computed by Adamo.

As mentioned previously, it is unknown what definition of sunrise Adamo used, but the author of the Orbitrack software replied to an email query and stated that Orbitrack uses the astronomical definition of sunrise (the time when the center of the sun's disk crosses the horizon). With this information, the Starry Night results could be compared directly with Orbitrack, whose accuracy is supported by its agreement with Heavens-Above predictions for other satellites. The Starry Night graphical display shows the center of the sun crossing the horizon at 20:38:09, about seven seconds later than Orbitrack.

The difference between the sunrise times suggests that the setting times of stars seen in the video are also about 7 seconds earlier than predicted by Starry Night, but still about 9 seconds later than the video time displays. However, it cannot be assumed that the 7-second error for sunrise also applies to the setting times of stars without knowing the details of how both programs model the positions of the spacecraft and the horizon over time. For example, Tom Van Flandern[vii] pointed out that it was not known whether Starry Night accounted for such factors as the ellipsoidal shape of the Earth and if not, how significant such an oversight would be to the computed transit times.

Rather than making further inquiries with Starry Night, a completely independent program was written that takes as input data generated by Orbitrack on the spacecraft’s longitude, geodetic latitude, and altitude as a function of time. This program will be referred to subsequently as "HCROSS," short for its function of computing the times of horizon crossings of stars. The HCROSS program takes into account the ellipsoidal shape of the Earth: it assumes an equatorial radius of 6378.1 km and a polar radius of 6356.8 km.

Briefly, the HCROSS program proceeds as follows: For each Orbitrack time step, the universal time is extracted and the geodetic data on the spacecraft's position is converted to the equivalent geocentric (spherical) coordinate system. The universal time is converted to the Greenwich Sidereal Time from which the longitude of a given star is then computed using the right ascension and declination for the star. From the star's latitude and longitude, the azimuth and angular altitude of the star from the spacecraft's nadir line are computed (the nadir line is the line connecting the spacecraft to the Earth's center). The angular altitude of the horizon in the direction of the star's azimuth is then calculated. The time at which the horizon's altitude exceeds the star's altitude indicates the point in time at which the star sets. Conversely, the point in time when a star's altitude exceeds the horizon's altitude marks the point in time at which the star rises.

A sample of Orbitrack output is shown in Table 1 for a time period that includes the STS-48 spacecraft sunrise for Orbit 44 (the orbit on which the objects appear in video). The sunrise as computed by Orbitrack is indicated by the point in time when spacecraft "Visibility," changes from "In Darkness" to "In Sunlight."

Table 1. Sample Orbitrack Output for STS-48 using the SGP4 Orbit Model. Orbital sunrise as computed by Orbitrack is in the third column at UT 20:38:02.

Date	UT	Altitude (km)	Latitude	Longitude (° W)	Visibility
09/15/91	20:38:00	571.8	-17.37	-115.61	In Darkness
09/15/91	20:38:01	571.8	-17.42	-115.65	In Darkness
09/15/91	20:38:02	571.8	-17.47	-115.68	In Sunlight
09/15/91	20:38:03	571.8	-17.52	-115.71	In Sunlight

As part of the verification of the correctness of the HCROSS program, it was used to compute sunrise as viewed from the Space Shuttle Discovery from a file that includes the data of Table 1 for a time period extending from 20:37:00 to 20:42:00 UT. For that brief span of time, the sun may be treated as a fixed star. Using an online astronomy calculator, the right ascension and declination of the sun for 9/15/1991 at 20:38:03 was obtained (RA: 11:32:27, DEC: 2°58.6').

The time of sunrise computed by HCROSS was 20:38:02 – the same time indicated directly by Orbitrack. While the output of the HCROSS program is dependent on the spacecraft position data and the orbit model used by Orbitrack (or any other application with similar capabilities), the rise and set times it computes are otherwise independent.

To further verify both HCROSS and Orbitrack, STS-48 data files generated by two other satellite-tracking applications were also used to determine the orbital sunrise. One of them was an application called WinTrack[viii], written by a NASA contractor engineer. The second was NASA's SkyWatch Java applet[ix].

Also, the orbital sunrise for the International Space Station based on a recent TLE was computed by three different methods. The results are summarized in Table 2. It can be seen that the various combinations of software and satellite produce results differ at most by 2 seconds. The small differences between them are probably due to differences in the precision of program output and integration step size rather than to inherent computational accuracy. OrbiTrack data will be the basis of the remainder of this article because it uses the smallest integration step size and reports spacecraft coordinates with the highest precision.

The very close agreement among the various satellite-tracking applications provides grounds for confidence in the accuracy of the HCROSS program when applied to the special purpose for which it was written: the computation of horizon transit times for stars in the STS-48 video sequence.

Table 2. HCROSS verification results. For HCROSS results, the satellite-tracking program used to generate spacecraft position data is shown in parentheses. The MacSPOC results are from Adamo in 1999. The program is no longer available online so was not checked directly. * NASA SkyWatch sunrise was interpolated from the solar altitudes at 20:39:51 and 20:38:01 with adjustment for SkyWatch's use of solar limb transit to compute satellite visibility rather than the sun's center as is the case for other software.

Application	**Satellite**	**Date**	**Computed Sunrise**
MacSPOC(Adamo)	STS-48	9/15/91	20:38:02
NASA SkyWatch *	STS-48	""	20:38:03
Orbitrack	STS-48	""	20:38:02
HCROSS (Orbitrack)	STS-48	""	20:38:02
HCROSS (WinTrack)	STS-48	""	20:38:01
Heavens-Above	ISS	3/8/03	03:32:22
Orbitrack	ISS	""	03:32:22
HCROSS (Orbitrack)	ISS	""	03:32:22

Accuracy of Orbital Elements

Regardless of the accuracy of the software, its output of course can be no more accurate than the input data, which raises the question of the accuracy of the NASA TLE data used to predict future spacecraft positions.

One indicator of the error margins in NASA's orbital parameters was provided by another event in the STS-48 mission that occurred only two hours after the events under discussion here. NASA computations predicted that the space shuttle was on a course that would bring it within 5 kilometers of a Russian satellite[x]. This was smaller than the distance that NASA flight safety policies permit space shuttles to approach other satellites. NASA took the unprecedented action of maneuvering the shuttle to maintain a safe distance between the two spacecraft. The collision avoidance burn increased the predicted distance of approach from 2.2 kilometers to 16. This suggests that the margin of uncertainty in NASA's orbital element data is at most 8 kilometers, since there would have been similar uncertainties in the predicted positions of the Russian satellite and the shuttle. The two margins would have added together to an uncertainty of less than 16 km in their relative positions. Indeed, according to TS Kelso, the Director of the Air Force Space Command Space Analysis Center at Peterson AFB in Colorado:

> "A new element set is issued [by NORAD] only when the position predicted by the current element set differs from that predicted by the new element set by more than a certain amount. In the case of the NORAD two-line element sets, that amount is five kilometers (with a 90 percent confidence interval)."[xi]

A distance of 5 kilometers is effectively the margin of uncertainty for the predicted positions of satellites in near-Earth orbit. At the orbital speed of the space shuttle of ~7 km/sec, an uncertainty in distance of 5 km translates to a time uncertainty of 5km divided by 7km/sec, or about 0.7 seconds.

The TLE data can become obsolete over time due to slight inaccuracies in the predicted atmospheric drag and to the cumulative effects of the firing of the spacecraft's attitude control thrusters. The frequency at which new TLE's are issued is thus a good measure of the reliability of a given element set for predicting astronomical events at a particular time. For this reason several of the officially released NASA TLE's for the STS-48 mission were examined. The TLE computed for an epoch time closest to Orbit 44, the orbit on which the events in the video sequence occurred, was a vector for Orbit 46 obtained from the Internet. In general, this would make it the most reliable for Orbit 44 computations. But that vector takes into account the effects on the shuttle's orbit of the collision avoidance maneuver that followed the events, so the most applicable official TLE is the one for Orbit 36, acquired by the author from the Johnson Space Center public information office. (All TLE data referenced here is given in the Appendix to this paper).

Rather unexpectedly, it was found that the time of the Orbit 44 sunrise predicted by Adamo's TLE disagrees with the prediction of the official Orbit 36 TLE by a margin of 6 seconds and with that predicted by the Orbit 46 TLE by 5 seconds. As shown in Table 3, the Orbit 44 sunrise predicted by the Orbit 67 TLE for an epoch time 35 hours later is still in closer agreement with the predictions of the TLE's for the two epochs that bracket Orbit 44 than is the Adamo TLE.

Table 3. Time of the Orbit-44 sunrise predicted by OrbiTrack based on the official NORAD TLE's for STS-48. ΔT is the difference between the TLE epoch time and the epoch for the Adamo TLE at Orbit 45 (ΔT = 0).

TLE Orbit #	ΔT (hours)	OrbiTrack Sunrise
36	-14.4	20:38:08
45(Adamo)	0	20:38:02
46	+04.7	20:38:07
53	+15.9	20:38:05
67	+35.2	20:38:05

At 20:38:07 UT, the Adamo TLE predicts the spacecraft to be at the geodetic coordinates 17.73 S, 115.85 E. For the same time, the Orbit-36 TLE predicts a position of 17.43 S, 115.63 E. The angular distance between the two predicted positions is 0.366 degrees, which translates to a linear distance of 44.4 kilometers. This error in position is nearly 9 times larger than the 5km margin that requires the issuance of a new state vector according to NORAD policy. That no new vector was released suggests that the TLE computed by Adamo is in error. Until some reason is found to the contrary, the official NASA Orbit-36 TLE should be considered accurate to within a distance of 5km as required by NORAD policy. The sunrise

and star transits occurring on Orbit 44 predicted by the official TLE should therefore be accurate to within 1 second.

Using the Adamo orbital elements, HCROSS computed the setting time for Polaris to be between 20:40:13 and 20:40:14 UT based on the data files generated by both WinTrack and OrbiTrack. Using the official NASA TLE for Orbit 36, Polaris would have set 6 seconds later, between 20:40:19 and 20:40:20 UT. In the STS-48 video, Polaris disappears before the displayed time reads 20:40:02 -- more than 11 seconds before the time of the star's setting predicted from the Adamo TLE and more than 17 seconds before the time predicted from the NASA TLE. Even if the Adamo TLE were to prove more accurate than the official TLE, the discrepancy would still be substantial.

Effects of the Earth's Atmosphere on the Observed Horizon Crossings of Stars

Van Flandern[xii] has noted that stars may disappear before reaching the true horizon, their light extinguished in the Earth's lower atmosphere where its density increases exponentially with decreasing distance from the Earth's surface. He argued that this could explain why stars seem to "set" prematurely in the video. Clouds could also block starlight. The cumulonimbus clouds that produce lighting can extend in height almost to the upper boundaries of the troposphere, an altitude of about 16km. It thus seems possible that starlight might have been extinguished within the troposphere somewhere below an altitude of 16 km and above the true horizon. An analysis by the author indicated that stars of Polaris' magnitude should have been visible in the STS-48 video at altitudes greater than about 13.4 km under normal conditions, leaving most of the video time differences between the video times of star disappearances and predicted horizon transits unaccounted for. Under normal circumstances, the stratosphere, which begins above 16 km, is quite transparent in comparison to the lower atmosphere.

However, circumstances were far from normal in September 1991. Three months earlier, on June 15, 1991, Mount Pinatubo in the Philippine Islands had erupted. This was one of the greatest volcanic eruptions of the 20^{th} Century. Among the many radical changes it produced in the Earth's atmosphere was a cloud of stratospheric sulfate aerosols that, by September, had circled the globe. The cloud layer was about 6 kilometers thick. The top of the cloud layer reached its maximum altitude of about 26 kilometers[xiii] in tropical latitudes. The cloud layer increased the "optical thickness" (defined as the natural logarithm of the ratio of incident to transmitted light) of the stratosphere by two orders of magnitude. To an observer on Earth, this was not sufficient to block the light from stars normally seen when they were near the zenith position. But stars close to the horizon that would have otherwise been visible would have disappeared prematurely.

From the vantage point of the camera aboard the space shuttle looking toward the horizon, stars would have disappeared abruptly at the level of the cloud layer rather than dimming gradually as they would have done otherwise. This is exactly what the STS-48 video indicates; stars much fainter than Polaris disappeared at video display times that differed from their predicted times of horizon transit by about the same amount as for Polaris. Under normal conditions, fainter stars should have disappeared more prematurely than brighter stars. For stars imaged when the shuttle was at more northerly latitudes and looking past the equatorial location of the cloud belt's maximum altitude, the time difference was actually less by several seconds for stars fainter than Polaris, which approached the spacecraft's horizon near the Earth's equator.

Clearly, this cloud layer was responsible for a substantial part of the time difference, but a large part of the difference was still unaccounted for. One approach taken to determining how much the cloud layer contributed to the measured video time discrepancies was to treat the top of the cloud layer as a solid opaque surface, effectively increasing the Earth's radius by 26 km, reducing the spacecraft's altitude by the same amount, and then running the HCROSS program with the altered parameters. When this was done using the NASA Orbit-36 TLE, a time difference of more than 7 seconds remained.

It could still be argued that the spatial distribution and optical properties of this transient cloud, produced by the very singular event of the Pinatubo eruption, are not well enough defined to have confidence that the remaining 7-second discrepancy is a real error in the video time display and not completely attributable to the optical effects of the cloud. However, there is an alternate method of estimating the time difference that is less dependent on assumptions about conditions in the Earth's turbulent lower atmosphere: the transit by stars of the permanent "airglow" layer of the Earth's upper atmosphere that begins more than 60 kilometers above the Earth's surface.

Star Transits of the Airglow Layer

In Figure 2 it can be seen that stars are crossing a bright line before reaching the horizon. This line marks the position of the maximum intensity layer of the airglow. Given a reliable value for the altitude of this peak-intensity layer, its predicted transit time by a star can be computed using HCROSS in the same manner previously described for the transient aerosol cloud from the Pinatubo eruption: adding the 87-km height of the layer to the Earth's radius and subtracting the same amount from the spacecraft's altitude. Being a permanent feature of the Earth's atmosphere, detailed information on the structure of the airglow layer is much more readily available.

The airglow is a complex region of the Earth's tenuous upper atmosphere at altitudes between 60 and 100 km. The glow is caused by light emitted when molecules dissociated by ultraviolet sunlight recombine. The intensity of the glow varies with solar activity, season, time of day, latitude, and many other factors. The photochemical reactions that produce the glow also vary with altitude. But the altitude of maximum airglow intensity is near a value of 87 km[xiv] and seldom varies by more than 2 kilometers, regardless of conditions in the lower atmosphere[xv]. At this altitude, the reactions primarily responsible for the glow involve hydrogen and ozone (O_3) combining to produce hydroxyl (OH) molecules. A typical graph of intensity versus altitude[xvi] for the hydroxyl layer is shown in Figure 3. It can be seen that intensities within 85% of the maximum are confined to a layer between altitudes of 84 and 89 km.

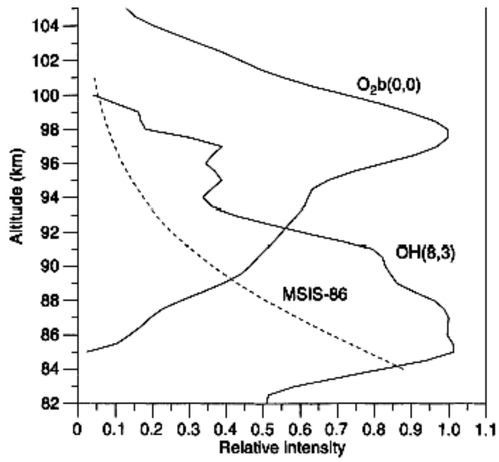

Figure 3. Emission profiles for OH and O_2 nightglow layers. These are relative intensities. The O_2 peak emission is many times less than the OH peak. (From Ref. xiv)

By coincidence, the 5-km thickness of this layer is about the size of one pixel in the frames captured from the STS-48 video at the distance from the camera to the horizon. For a preliminary estimate the transit time of this layer by Polaris in the STS-48 video, the contrast and gamma values of several video frames were adjusted so that only the pixels near the maximum intensity along the airglow boundary have non-zero values (i.e., are not completely black). Three of these frames from points in the video 1 second apart are shown in Figure 4.

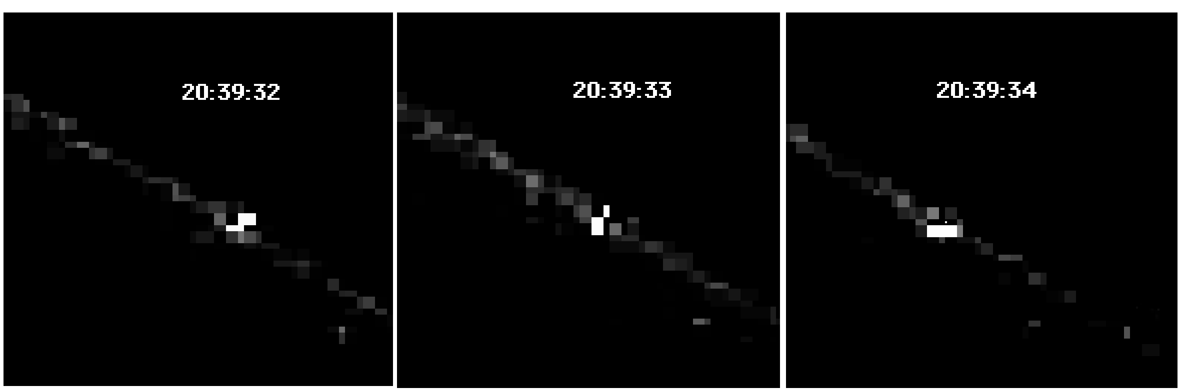

Figure 4. Three frames showing Polaris near transit of the peak-intensity airglow boundary and the corresponding video time stamps. Pixels containing light from Polaris less than the maximum value have been blacked out, since the actual position of the star should be in one of the pixels of highest intensity.

In the first frame of Figure 4 Polaris seems to be just above the airglow boundary and just below it in the last frame. It appears to straddle the boundary in the middle frame at 20:39:33. This indicates that the transit of the highest-intensity shell of the nightglow layer might have occurred between 20:39:32 and 20:39:34 UT.

While the transit must have occurred "around" that time, the actual moment of the transit cannot be determined with any measure of confidence from just these three frames. The apparent discrepancy between the video display time and the predicted transits of stars is a matter of seconds and it takes more than one second for a star to move one pixel. During this slow progression of stars in the video, the airglow layer and stars appear to "shimmer," moving back and forth slightly as the video is advanced frame by frame. However, there are literally hundreds of frames of video, and a standard method exists to exploit them: a linear least-squares regression.

The least-squares method not only can yield an objective estimate of the "best fit" line for noisy data, but a statistical measure of the confidence in that estimate. It was applied to the problem of determining the time of Polaris' transit of the airglow layer as follows:

- A total of 58 images were extracted from video frames within a 24-second time span, noting the video display time for each frame. The time span was chosen so that the transit time estimated by visual inspection would be near its center.

- As was done for the three images in Figure 4, the contrast and gamma values were adjusted in each image so that only the highest-intensity shell of the airglow layer and Polaris were visible. Other stars and extraneous objects that were not removed by these adjustments were blacked out manually (the only manual part of the process).

- Each image was then scanned by a program that determined the position of Polaris and points of maximum intensity of the airglow layer.

- The line described by the "horizon" of the airglow shell in each image was determined by a least-squares regression routine and the distance from that line to Polaris was computed.

- A final least-squares regression was done to obtain an equation describing the best-fit line for the distance between Polaris and the airglow layer versus the video display time. The X intercept, or the point on the time axis where the distance = 0, was taken as the estimate of the time at which Polaris crossed the peak-intensity airglow shell.

A plot of the resulting distance-versus-time data points and the best-fit line are shown in Figure 5. On this graph, the distance between Polaris and the airglow shell is on the Y-axis and the video display time in seconds starting at 20:39:20 UT is on the X-axis.

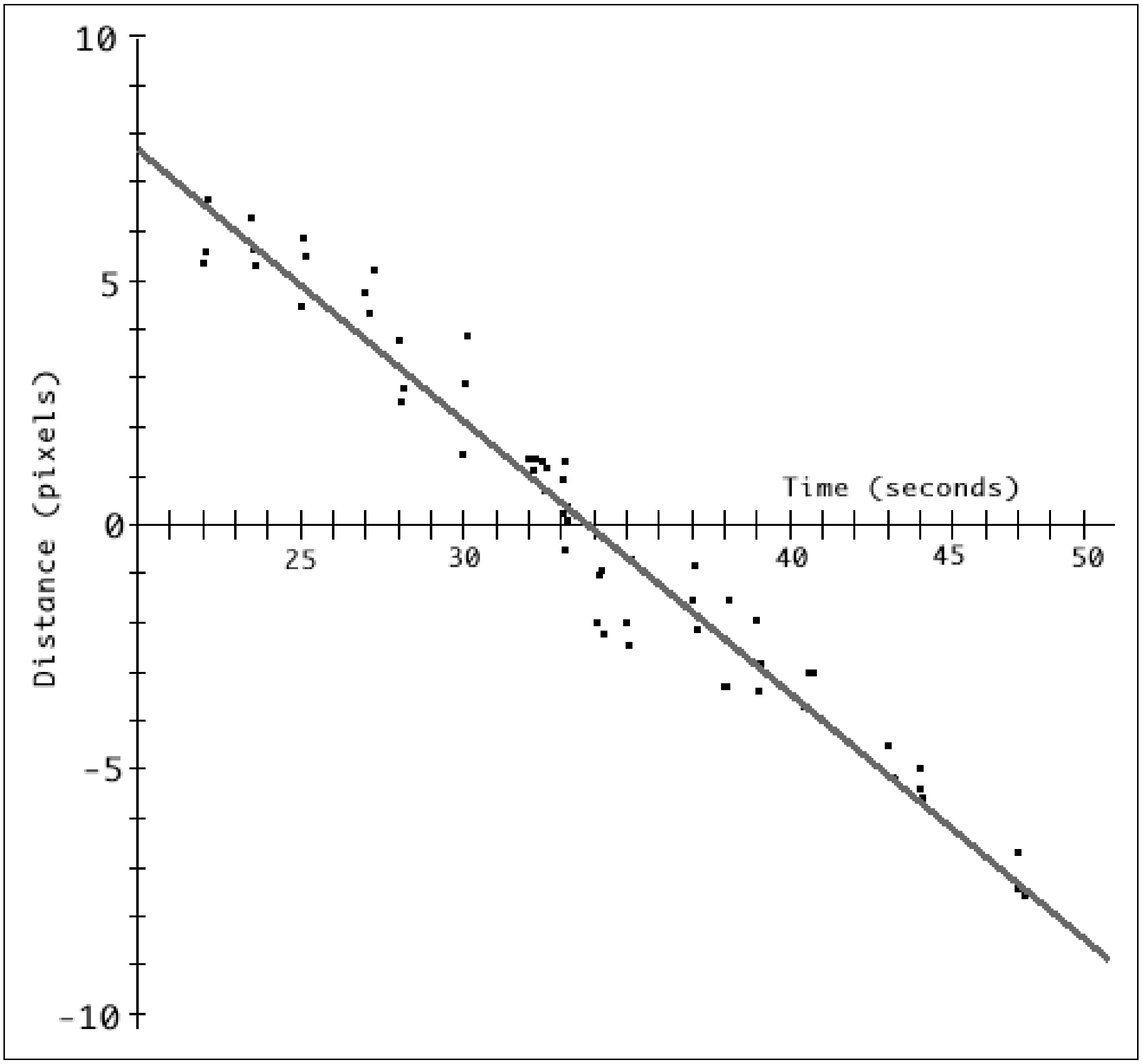

Figure 5. Graph of least-squares regression line indicating a Polaris transit of the peak-intensity OH nightglow layer from the perspective of the space shuttle Discovery at video display time 20:39:33.9 UT, September 15, 1991. Distance is 0 at moment of transit. Time is seconds from 20:39:00 UT on the video display.

The primary value of interest in this graph is the X-intercept – the value of time at the point where Y = 0, indicating the moment that Polaris transited the peak-intensity airglow layer. The computed intercept value was 20:39:33.9 UT. From the standard statistical formula, the .005 probability confidence interval computed for this intercept was 0.3 pixels. In other words, there is less than a 0.005 probability that the true distance value is greater than 0.3 pixels from the peak-intensity airglow layer at that time.

From the HCROSS output and measurements on the video frames, it is known that Polaris is moving at a rate of 0.57 pixels per second relative to the horizon[1]. If the true distance to the peak-intensity airglow layer is 0.3 pixels greater than 0 at the computed X-intercept, then the true time of the transit was 0.3 pixels divided by 0.57 pixels per second, or 0.53 seconds later than what is indicated by the estimated intercept. This means, in effect, that the probability is less than 1/2 of one percent that the video clock display at the moment of Polaris' transit of the peak-intensity airglow shell was greater than 20:39:34.4 UT.

In general, the primary purpose of a linear regression is to estimate the slope of a line from noisy data in order to test for a correlation of the Y-values with the X-values. (If the slope is zero it is concluded that the value of the Y variable is independent of the X variable and therefore that there is no correlation between them). But as noted previously, the slope in this case is independently known to be to be 0.57 pixels per second. The known slope can therefore be used as a check on the validity of the computed regression line's estimated slope and therefore on the validity of the method used to generate it. The slope of the computed regression line shown on the graph is 0.552 pixels per second, and the known slope differs from it by only .02 pixels per second. This difference is well within the .005 confidence interval, indicating that the method is providing valid results. (A difference larger than the .005 confidence interval would be an improbable result, indicating a likely flaw or systematic error in the method).

The time of Polaris' transit of the 87-km airglow layer computed by HCROSS using data generated by OrbiTrack for the Orbit-36 TLE was 20:39:42. The confidence intervals can therefore be used to state that there is a 99.5% probability that the discrepancy between the video time display and the actual time of the transit is equal to or greater than 7.6 seconds, assuming the TLE data are correct. Allowing for a possible 1-second error in the TLE data, that difference might be reduced to 6.6 seconds. Note that this is very close to the value arrived at independently by simply assuming that the stratospheric aerosol cloud from the Pinatubo eruption formed an opaque layer 26 km above the Earth's surface.

The time discrepancy, then, still appears real and would be too large for any causal link to have existed between the light flash and the thruster firing[2]. The 1.2-second thruster impulse ended at 20:39:24.99 UT. If 6.6 seconds is added to the time displayed on the video frame that shows the first evidence of the flash, the flash event occurred no earlier than 20:39:31.2, and the thruster was inactive for more than 6 seconds prior to the light flash.

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[1] The rate of motion is 0.61 pixels per second in a direction 70 degrees from the horizon, so the component of velocity perpendicular to the horizon is .61 pixels/sec multiplied by the sine of 70 degrees.

[2] The discrepancy would be 6 seconds less based upon the Adamo TLE, placing the light flash at about one second after the thrusters ceased firing. It might be argued that this smaller difference is due to other sources of error and does not indicate any error in the video display time. But the reasons to doubt the accuracy of that TLE previously described would also have to be addressed.

The True Nature of the "Flash"

The star setting computations provide grounds for reasonable doubt that the L5D thruster firing caused the flash of light to which the objects in the video reacted. But an interesting question still remains: What did cause it? It may seem difficult to imagine what else besides flames from a thruster entering the camera field of view could have created a flash of light in the vacuum of space. The video itself may provide the answer, quite independently of the astronomical timing issue.

A fraction of a second after the flash, several "projectiles" are seen to come from the lower left corner of the image field -- the general direction of the aft thruster units on the shuttle. When the video is viewed at normal speed, this conveys the impression that the flash of light must have come from the same direction as the projectiles. But on running the video frames in slow motion, it becomes obvious that the light flash originated from the upper left corner of the video where the lens flare already was present, and not from the lower left corner. In fact, the light flash seems most likely to have been an intensification of the lens flare. This is illustrated by the brightness contour images of Figure 6.

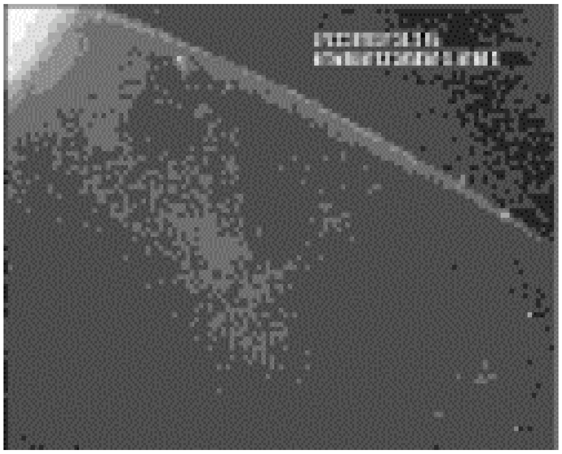
These contour images were created by dividing the 256-value gray scale digital number (DN) range into equal intervals and setting the brightness of each pixel to the nearest interval value lower than the pixel's own (the "floor" of the brightness interval the pixel occupies).

The contour image of the pre-flash frame of Figure 6A shows a relatively uniform brightness distribution, with the glare from the upper left corner extending diagonally to the lower right. The intensity of the flash is at its maximum in the frame of Figure 6B, indicating that the increased brightness is an expansion of the lens flare about this diagonal axis.

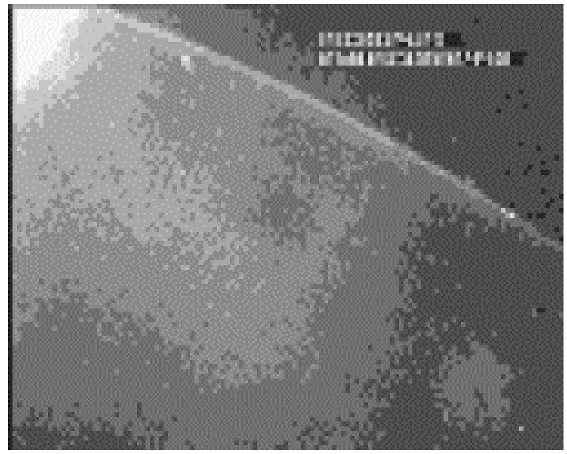
Light intensity is additive, so it may seem possible that a small increase in brightness at the lower left corner caused by rocket exhaust was responsible for the enhancement of the lens flare in Figure 6B. To determine if this was the case, the pre-flash frame of Figure 6A was subtracted from the frame of Figure 6B and the contour image of Figure 6C was generated[3]. The difference image shows how much intensity was added at various points. It shows no evidence that the added light intensity was greatest at the lower left corner, or even that it was distributed uniformly over the image. Instead, the contours of the difference image shows the intensity gradients increase in a markedly concentric pattern toward the upper left hand corner at the point where the lens flare was already the greatest. (The area adjacent to

[3] The relationship between input light intensity and signal output by a camera is often not linear, so the difference in the brightness between two frames at a particular pixel position may not be precisely proportional to the difference in input light intensity. However, in order for a uniform increase of input light intensity to increase the output brightness of already-bright areas more than darker areas, the camera's response curve must be such that the slope of the curve increases with increasing light intensity. In the resultant images, this would tend to increase the brightness of brightly illuminated features relative to dimly illuminated features such as stars -- something that seems implausible for a camera designed for low levels of lighting.

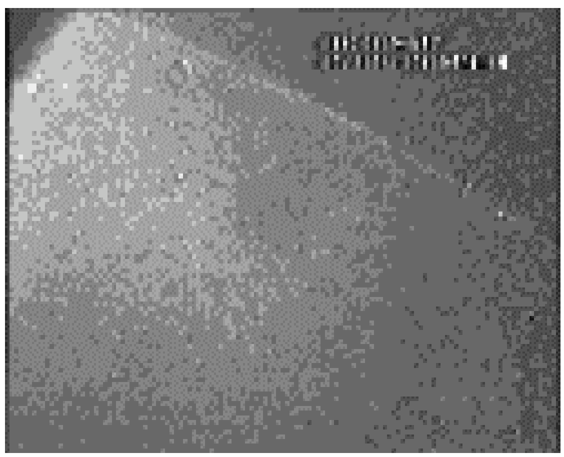
the upper left corner is dark because that region was saturated (DN 255) in both frames, so the difference in brightness between them is zero).



A. Frame preceding flash.
20:39:21
DN interval size 32



B. Frame at maximum flash intensity.
20:39:22.449
DN interval size 32



Difference image.
Frame A subtracted from Frame B
DN interval size: 13

Figure 6. Brightness contours for a pre-flash frame, a frame showing the light flash, and for a difference image created from the two frames. The shuttle's aft attitude control rockets are located below and to the left of the lower left corner of the images.

The lens flare preceding the flash is sunlight, but not rays of the sun directly entering the optical path of the camera. The camera was in the shadow of the shuttle's body and was pointed away from the sun. The lens flare is a portion of the light scattered in all directions (as opposed to specular, or mirror reflection) from light-colored shuttle surfaces exposed to the sun after orbital sunrise. Oberg has suggested that a disk-shaped antenna on the right side of the shuttle near the crew cabin was probably responsible for sunlight entering the camera, which was on the left side of the shuttle in the aft area of the cargo bay. Figure 7 shows a sketch approximating this lighting geometry.

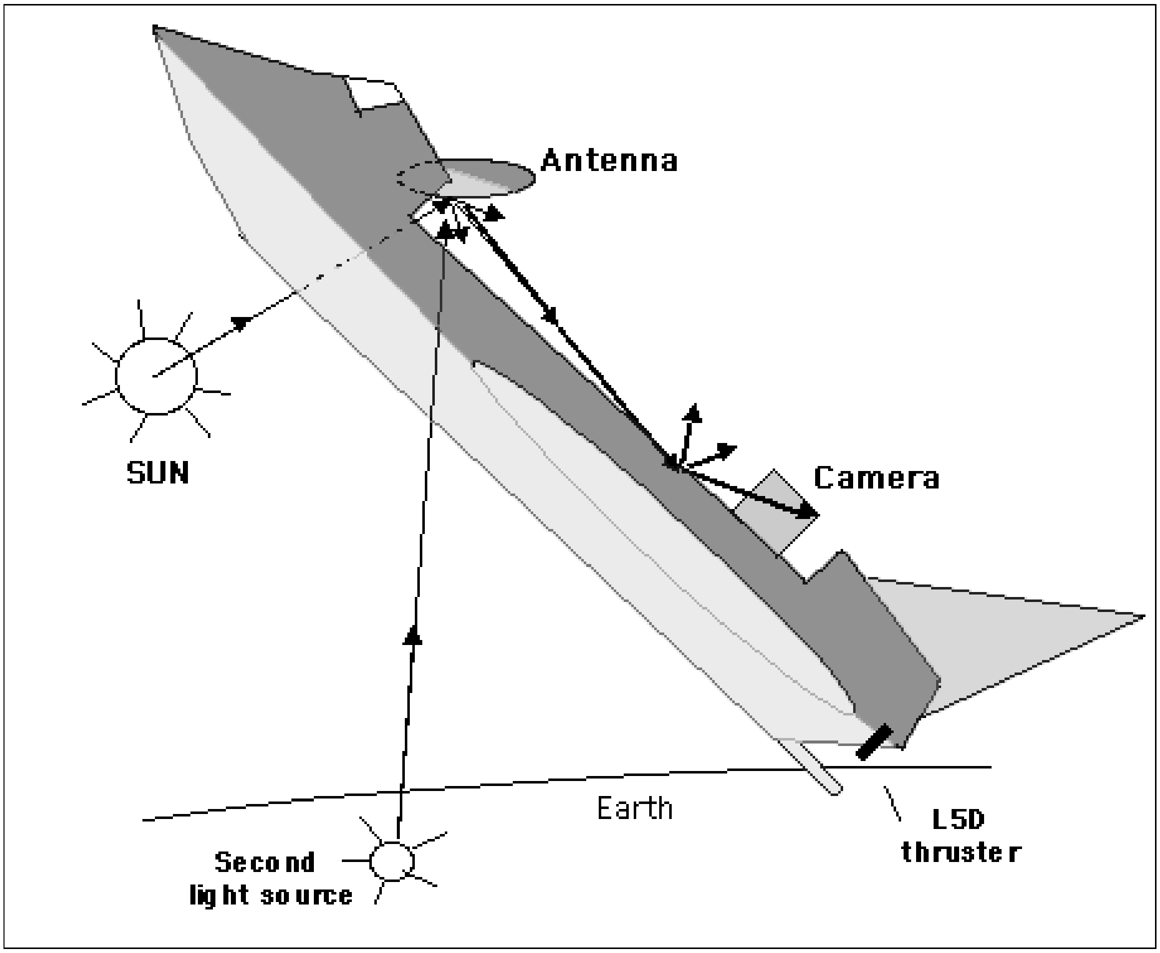


Figure 7. Sketch of approximate lighting geometry that produced the lens flare seen in upper left corner of the STS-48 video. Dotted lines indicate where rays from the sun pass on the right side of the shuttle. Multiple arrows extending from the antenna and shuttle body surfaces denote diffusely scattered light from those positions. A proposed second light source is shown near the Earth. Camera line of sight is toward the viewer and downward toward the Earth.

At the bottom of the sketch is a second hypothetical light source that seems the most reasonable explanation for the intensification of the lens flare that constitutes the flash. Rays from this light source are shown reaching the antenna from the left side of the shuttle, although the light source could have just as easily been positioned so that its light reached the antenna on the same side of the shuttle as the sun. In either case its light would add to the sunlight entering the camera. To intensify a specular reflection, a second light source must align precisely with the first source. But for non-mirror-like ("Lambertian") surfaces that scatter light in all directions, only the final legs of the paths followed by the light from the two sources need be the same. Since the lens flare seen in the video was almost certainly the result of diffusely scattered sunlight, a second light source would need no special alignment with the camera, shuttle, or sun in order to increase the brightness primarily at the position of the already-present lens flare.

To make such a noticeable contribution to the existing lens flare caused by the sun, the brilliance of this second light source would have to have momentarily rivaled that of the sun. It seems very unlikely that the "back-splashed" flame from the small attitude control thrusters proposed by Oberg could be responsible. Most of the exhaust gases from the L5D and R5D thrusters are directed downward away from the camera, and the light from any flames they produced would be most intense in that direction. That light could not reach any surfaces on the upper portion of the shuttle's body. Only the faint glow from the peripheral exhaust reflected from the body flap on the back of the shuttle could add to any illumination entering the camera by way of the antenna on the opposite end of the shuttle. The intensity of light is inversely proportional to the square of the distance from the source, which would be almost twice the length of the spacecraft if it originated from one of the aft thrusters.

Bruce Maccabee has suggested that the light flash might have been caused by a specular reflection of sunlight off some shuttle surface momentarily aligned in the right way with the sun and the camera[xvii]. However, the spacecraft's orientation relative to the sun changes slowly as it orbits the Earth. With the possible exception of the antenna, which conceivably could have been rotated to pick up a new tracking station, nothing on the shuttle would likely have been in motion at the time. It seems almost certain that the objects in the video were responding to whatever caused the light flash. The behavior of objects in space, either near or far, would not have been affected by a glint of reflected sunlight from a shuttle surface. Quite apart from the objects seen in the video, this light flash remains an unexplained and remarkable anomaly.

Coincidence

Despite what the author views as compelling evidence that there was no connection between the thruster firing and the light flash, it may still seem that even a span of time of a few seconds between the two events is far too close to be coincidental. But after taking into consideration the frequency of thruster firings on the space shuttle, it can be seen that this time span is not really close in any meaningful statistical sense. The shuttle attitude rate-error chart obtained by Oberg indicates that there were 5 thruster firings in a 6-minute time span that includes the light flash --one firing every 120 seconds on average.

The situation could be viewed as a simple binomial probability problem in which there were five "trials" -- the five thruster firings. Each trial would have a probability of success of 12/320 if the criterion for success were that a thruster fired within, say, 6 seconds of the light flash over the 320-second time span. For a binomial distribution, there is a 16% chance of one or more successes after 5 trials with a probability of 12/320 for each individual trial. By convention, a statistical result is not generally considered significant unless the cumulative probability is less than 5%, or sometimes 1%. So there is no apparent reason for regarding the proximity of the L5D and R5D thruster firing to the light flash as having any statistical significance.

The second coincidence cited as evidence of the prosaic nature of the STS-48 objects is that they appeared very close to an orbital sunrise. But it is clear that they did not appear close enough to sunrise for any causal link to have existed. The sun moved at a rate of .034 degrees per second relative to the horizon from the viewpoint of the shuttle. The solar disk is about 1/2 degree in angular diameter so more than 15 seconds elapsed between the time the leading edge of the solar disk cleared the horizon and the time that the full disk was visible from the shuttle.

As was shown in Table 2, all of the satellite tracking programs used with Adamo's TLE indicated that the center of the sun crossed the horizon at about 20:38:02 GMT, while the video time display indicates that the first of the objects, "M0," appeared at 20:38:09. The leading edge of the sun would have appeared about 20:37:55. Further, the Earth's atmosphere is refractive and bends the sun's rays around the horizon by an angle of about 1/2-degree -- approximately one solar diameter. This would have advanced the "optical" by about 15 seconds. Any debris particles in the vicinity should thus have been exposed to sunlight beginning at about 20:37:40, at least 29 seconds before the objects started to appear, according to the Adamo TLE. The optical sunrise would have preceded the appearance of the object by 23 seconds according to the NASA Orbit-36 TLE. If the apparent inaccuracy in the video time display is taken into account, several more seconds must be added to the time elapsed between sunrise and the appearance of the first object.

It might still be argued that a swarm of debris particles happened by chance to emerge from the spacecraft's shadow and enter the camera's field of view shortly after sunrise. But then there could be no causal connection between sunrise and the appearance of the objects; it would be a meaningless coincidence. In contrast, a meaningful coincidence is at least possible if it is assumed that the objects were intelligently controlled vehicles.

While it is not the purpose of this paper to engage in such a speculation, it seems worth raising in relation to the question of coincidences. The activities of most forms of life, including humans, are organized around the position of the sun, with sunrise being one of the most important markers of the passage of time. It does not seem altogether implausible, then, that the objects appeared near sunrise because that was a convenient and natural time to schedule some sort of coordinated operation. If object M0 originated from a point on Earth close to where it first appears in the video, it would have been about an hour before dawn, local time.

Revised Timeline

The proposed timeline of events in the STS-48 video is listed in Table 4.

Table 4. Revised timeline of events recorded on the STS-48 video.

Revised Time (UT)	Event
20:37:46	Optical sunrise begins
20:38:01	Optical sunrise complete, but solar disk still distorted by atmospheric refraction
20:38:16	Astronomical sunrise complete, full and undistorted solar disk visible
20:38:16	Object M0 appears
20:39:23.31	R5D thruster begins firing
20:39:23.79	L5D thruster begins firing
20:39:24.99	Both thrusters stop firing
20:39:32	Lens flare suddenly intensifies in the video

This timeline is based upon the estimated discrepancy of 7 seconds between the video time display and the airglow transit of Polaris as computed from the Orbit-36 TLE, allowing for atmospheric effects and 1 second of error from other sources.

Conclusion

To date, evidence both for and against a prosaic explanation of the STS-48 video sequence seemed almost equally compelling, creating a puzzling logical conflict. It is my opinion that the evidence presented here resolves that conflict. The astronomical timing considerations give negative evidence against the preeminent prosaic explanation for the objects: debris particles suddenly set in motion by the firing of a space shuttle rocket. The properties of the light flash described here are not only negative evidence against that explanation, but also positive evidence of an extraordinary event captured by the video camera of the STS-48 mission.

While shuttle debris and celestial bodies have, in fact, sometimes been misidentified as anomalous objects, there is a small but significant number of objects captured in space shuttle images that appear to be genuine anomalies, including those seen in the STS-48 video. Unlike videos and photographs of alleged UFOs taken by the general public, ancillary scientific data is usually available for NASA images and their authenticity is beyond any reasonable doubt.

The STS-48 video was perhaps the first evidence for anomalous objects above the Earth's atmosphere to have been acquired by a space shuttle mission, but was certainly not the last. A similar video sequence taken on the STS-80 shuttle mission was, if anything, even more remarkable. Several others taken on more recent missions might also bear closer investigation. It is my hope that this paper will in a small way provide a motivation for renewed scientific interest in such space shuttle imagery.

Acknowledgements

I wish to thank Amy M. Gabriel of Trajectory Operations at Johnson Space Center, Bill Bard of BEK Enterprises, and Tom Anderson of Starry Night for answering my many questions on their satellite-tracking software. I also would like to express my gratitude to Stella Milo and several other experts in upper atmospheric phenomena who were kind enough to answer my queries on their fields of study. Finally, I would like to thank Tom Van Flandern for bringing his expertise in astronomy to bear in defense of the prosaic explanation, which he favors. His input helped, I think, to put the arguments presented here on a sounder footing. I believe that expert opinions are always open to debate but should never be ignored.

Appendix: State Vectors for the STS-48 mission referenced in this paper

For a description of the TLE format see:
http://celestrak.com/NORAD/documentation/tle-fmt.shtml

Orbit-45 TLE computed by Dan Adamo:

```
1 99048U 91048A   91258.88919657  .00088917  00000-0  14277-3 0  9043
2 99048  56.9843 227.5621 0007503 305.7971  54.2522 14.99906509   450
```

The official NASA TLE for Orbit 36 was acquired from the Johnson Space Center information office. The other three are taken from:
http://celestrak.com/NORAD/archives/STS/sts-48.txt

Orbit 36
```
1 99999  00000NAS 91258.28936092  .00100000  00000 1  00000 1 1    15
2 99999  56.9870 229.9769 0006890 301.5098  58.5420 14.99736520   364
```

Orbit 46
```
1 21700U 91 63   A 91259.08333333  .00002987  00000-0  25599-3 0   205
2 21700  56.9866 226.7772 0007436 318.0037  10.6890 15.00279860   469
```

Orbit 53
```
1 21700U 91 63   A 91259.55208333  .00002983  00000-0  25599-3 0   237
2 21700  56.9861 224.8880 0007911 321.8756  19.3220 15.00229988   538
```

Orbit 67
```
1 21700U 91 63   A 91260.35519826  .00002980  00000-0  25599-3 0   269
2 21700  56.9864 221.6509 0007648 319.4895  40.5553 15.00209607   674
```

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[vi] Orbitrack software may be downloaded from http://home.tampabay.rr.com/k4lk/obtk.htm
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[x] STS-48 Mission Highlights (NASA) http://spacelink.nasa.gov/NASA.Projects/Human.Exploration.and.Development.of.Space/Human.Space.Flight/Shuttle/Shuttle.Missions/Flight.043.STS-48/Mission.Highlights
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[xvii] Email correspondence.