# Online Supplement to the 22 September 1979 Vela Incident: The Detected Double-Flash

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## Dynamics of interplanetary dust

Whilst dust grains in the solar system are subject to several forces, their relative contributions are dependent on particle properties (especially size and/or mass, electric charge, plus morphology and composition) as well as heliocentric radius. The eventual distribution of interplanetary dust is thus a very complex problem.[1]

Gravitational attraction by the Sun is the most obvious force, dominating for particles more massive than $10^{-8}$ g such that they are in Keplerian orbit about the Sun.[2] Gravitational interaction with a planet also influences their motion, and through orbital resonances can create dust rings such as the ~ 0.4 AU wide circumsolar ring discovered at Earth's orbital radius of 1 AU.[3]

For smaller grains, other forces can dominate. One is solar radiation pressure, which exerts an outward force for sizes less than about 1 μm. The Lorentz force causes charged grains to spiral in planetary or interplanetary magnetic fields and is orders of magnitude greater than the gravitational force for grain sizes around 0.01 μm.[4] Another very important process is Poynting-Robertson (PR) drag, in which grains larger than about a micron lose angular momentum, due to tangential-acting solar wind and radiation pressure forces, and so spiral in toward the Sun.

Thus, along with accretion by planets, or at least those with atmospheres, there are several mechanisms by which dust is lost to the solar system. Since such mechanisms can act over relatively short timescales, e.g. tens of thousands of years for PR drag, then other processes must occur to replenish the dust and maintain the observed steady-state population. This probably arises through a collisional equilibrium process, and includes mutual collisions between asteroids and/or Kuiper Belt objects, meteorite impacts with (atmosphere-less) planets or their moons, and even volcanic activity on some moons.[5] Other sources are comet breakup and the flux of interstellar dust always entering the solar system.[6]

Questions remain, but the expected result is that a heliocentric radial gradient in the particle size distribution is set up, with smaller size particles, e.g. < 100 μm, being preferentially removed by inward PR drag and/or outward radiation pressure, and larger ones, e.g. ≥ 100 µm, removed by collisional grinding down to smaller sizes.[7]

## Hypervelocity impact in the context of Vela's 5 & 6 and Alert 747[8]

Hypervelocity impacts (HVI) involve collision speeds of several kilometers per second or more. During such impacts a shock is formed, compressing and heating the collider (impactor) and target as it propagates through them. Depending on collisional parameters (collider composition and kinetic energy, target material, as well as impact angle), the pressure of the propagating shock wave front exceeds material strength properties (e.g. various elastic moduli) down to a certain depth, permanently damaging these materials. In most cases relevant to this work, the collider is destroyed, possibly vaporized, and a crater is gouged on the impacted surface as fragmented, melted and otherwise structurally failed material is ejected.

Given the potentially catastrophic implications of a meteorite hit on a spacecraft, and the ever-increasing amount of orbital debris, there is a large amount of literature on HVI collisions. This includes laboratory experiments, theoretical considerations, modeling and in-orbit experience of damage to many spacecraft, e.g. solar cells of the Hubble Space Telescope (HST), the Long Duration Exposure Facility (LDEF) and the European Retrievable Carrier (EuReCa) experiment.[9] These show that – as might be expected – the kinetic energy of the incoming particle is converted into radiation (e.g. a brief flash of light), mechanical work to excavate the crater and kinetic (and rotational) energy of a multitude of debris particles. The debris could have a collective mass a few orders of magnitude larger than the original collider and thus number in the hundreds or thousands of individual particles.

HVI typically results in three classes of debris, broadly termed jet, cone and spall.[10] These have been schematically depicted in Figure 6a of "The 22 September 1979 Vela Incident: The Detected Double-Flash." For impacts from head-on down to about 60 degrees from normal[11] the behavior of the debris is approximately equivalent. In a roughly temporal sequence, jetting occurs first and mostly along a plane parallel to the surface, and always forms a minor component of the debris. Secondly, many relatively small and fast moving particles – with velocities up to and even larger than the impact speed – are ejected within a narrow range of elevation angles and thus form a cone shaped debris cloud traveling along similar trajectories. The elevation angle has been observed to range from about 35 to 70 degrees, increasing as the crater depth increases during the impact, and thus also with impact velocity.[12] Finally, a much smaller number of larger and slower moving debris particles – 10 to 100 m/s – are ejected via a spallation process. This occurs when fractured material near a free surface of low tensile strength material ruptures, e.g.

when hit by a reflected rarefaction (or tension) wave. The spall fragments are ejected normal to the surface.

To strike somewhere on the six panels neighboring the bhangmeter plane the allowable incoming meteoroid trajectories sweep through an angle of about 240 degrees, mostly originating 'below' the spacecraft (where 'below' is toward Earth, measured from the plane defined by the hexagonal 'waist' of the satellite). But as an examination of Figure 6 shows, even for these there are some trajectories disallowed that would otherwise hit one of the six panels. For instance, the second collision site (ii) in Figure 6a has the same incoming meteoroid trajectory as (i) but hits the opposite panel, thus crossing the sensors field-of-views (FOVs) at a large angle to the optical axis, and near the satellite. This suggests that it could itself trigger the bhangmeters if sufficiently bright, as a steep signal rate of change is guaranteed for any reasonable velocity.[13] Such a grazing collision would also be unlikely to send much if any debris into the FOVs, instead dispatching the bulk on a diverging path. Similarly, in Figure 6b a range of incoming trajectories could be envisaged for which it is difficult to see how debris would either trigger both bhangmeters or result in near-identical first pulses.

In the specific collision depicted in Figure 6a the cone elevation angle has been drawn at 45±10 degrees, and in this case the debris is directed into the FOVs. But this is still no guarantee of a trigger since much of the velocity component of the debris is parallel to the bhangmeter optical axis, and the time rate of signal change may not be sufficient to trigger one or both sensors. This gets worse for increasing cone elevation angles, and in this case the absolute irradiance level may also be an issue as the debris cloud might be too distant and too dispersed – and thus too faint – to satisfy the second trigger criterion. Also, even if they did trigger it might be expected that a longer lasting initial pulse would occur, or at least one with a longer decay time, since the debris stays in the FOV far longer than for a predominantly transverse path.

On the other hand, for decreasing elevation angles other problems arise. This might occur for oblique collisions, say with an impact angle more than 60 degrees from the surface normal, and where the cone becomes flattened to eject more debris in the downrange direction. Assuming again that the geometry in Figure 6a is roughly correct, only for cone elevation angles less than 15 degrees would the perpendicular (to the bhangmeter optical axes) component of the velocity vector dominate. This provides a good chance for the bhangmeters to trigger, but then it is very difficult to see how the ejecta would pass through the FOVs at a height of more than about 1.5 m, required to achieve such similar first pulses.[14] In fact this critical elevation angle to ensure identical first pulses changes with impact point on the six solar panels. Rough guesses for the distance between possible impact points and the bhangmeter entrance apertures shows the elevation angle must be greater than about 30, 40 and

50 degrees respectively for collisions in the lower, middle and upper portions of the six panels for cone debris to pass 1.5 m above the bhangmeters. The same trigger criterion and signal shape problems outlined in the preceding paragraph then come into consideration.

Similar considerations also argue against debris from glancing (or oblique) collisions, otherwise known as ricochet.[15] In these cases only a few particles might be produced, e.g. as the meteorite merely breaks into pieces, depicted schematically in Figure 6b. But then there would be no trailing debris cloud to provide the second pulse. Also, since the first pulse may have been produced by a single particle ("first or first several" as stated by the Ruina panel) it would presumably have several of the same severe restrictions on its properties and trajectory as stipulated in the main article for the single or double particle cases.[16]

Finally, whilst an angle of 30 degrees has been 'assumed' between the bhangmeter plane and those of the neighboring six solar panels, it cannot be much less than this judging from photographs, whilst a higher value would only enhance the geometrical 'shield' property.

## Vela and the Pioneer 10/11's Asteroid Meteoroid Detector Event Data

At the time of the Ruina panel's deliberations, the only space-borne data feasibly relevant to Vela was from the Pioneer 10 and Pioneer 11 spacecraft, both equipped with optical and impact detectors, respectively the Asteroid Meteoroid Detector (AMD) and the Meteoroid Detection Experiment (MDE). The (unexpected) two order of magnitude enhanced detection rate of the AMD over the MDE was used by the Panel to support their contention that Alert 747 was merely a member of the Vela zoo population. But in using the AMD data to support their conclusion that a collision event on the Vela satellite was probably responsible for the Alert 747 signal, through solar reflection off debris particles, the Panel may have been misguided.

Because Vela was orbiting earth at a constant distance from the sun whilst the Pioneers travelled from 1 AU outwards, Vela would be expected to see a constant meteoroid event rate, while the Pioneer spacecraft would not.

The Pioneer MDE detected a continuously decreasing event rate between 1 and 5 AU, covering about an order of magnitude in flux (in units of $m^{-2}.s^{-1}$) and consistent with interplanetary dust models.[17] If the enhanced AMD trigger rate really was due to it 'seeing' collisional debris, then logically one might expect it to show a similarly decreasing event rate with heliocentric distance. This would be irrespective of the particle size range to which the respective instruments responded, since regardless of size the number density of particles (in $m^{-3}$) is a decreasing function of increasing distance from the Sun. Further, the inverse square law diminution of solar radiation would mean that the reflected light from the supposed collisional debris would get fainter with increasing distance.

It was not the case, however. The AMD saw a constant event rate with increasing heliocentric distance, at least out to around 3.5 AU. After this it detected no more events for both Pioneers, despite still being operational up until the time it passed through the Jovian radiation belts at around 5 AU.[18] Both the constant event rate and abrupt cessation of triggers was, and still is, a mystery, casting suspicion over reliability of the data.

The AMD was not able to provide time histories, i.e. signal strength as a function of time. Rather it only provided entry and exit times, with microsecond accuracy, peak intensity and total event duration. So, a direct comparison to any Vela signal, nuclear or otherwise, was obviously impossible. But despite having a FOV comparable to that of Vela the AMD did not see an event any longer than 38 ms for Pioneer 10 and 63 ms for Pioneer 11 (see also Figure 4). These are obviously much less, by about a factor of up to 10, than for Alert 747 or a nuclear explosion of 1 kt or greater, but like at least some of the Vela zoo events. Indeed, a comparison of the AMD and Vela zoo-on event histograms as functions of intensity and duration in Figures 12 and 13 respectively of OJ80 (Oetzel and Johnson, Vela Meteoroid Evaluation, 1980), reproduced in Figure 4, shows they have broadly similar forms, suggestive – but not proof – of a physical connection.

This duration difference is a significant consideration in assessing the origin of Alert 747. If the latter is from the same population of events – a total of 283 for AMD[19] and a hundred or so Vela zoo-ons – and/or produced by the same physical process, then how can its duration be so much longer? OJ80 extrapolated to longer times a subset of the AMD duration histogram, being the brightest events during the approximately 4-month traverse between 1 and 2 AU and which had durations between about 1 and 38 ms. Using a $t^{-1}$ or $t^{-1.5}$ form, respectively suggested by the AMD data itself and theoretical considerations, they suggested that the AMD would see an Alert 747 signal duration of 380 ms every 3–10 years. But the extrapolation was based on no extant data at such long durations even for the entire set of AMD events, and the AMD distribution itself flattens below 1 ms and drops steeply before 100 ms, not apparently fitting either a $t^{-1}$ or $t^{-1.5}$ form.

Interestingly the OJ80 3-10 yr interval between Alert 747-type event durations resembles the statement in the Ruina report that "Estimates show that such a collision can reasonably lead to the observed signal during the 10 years or so that the Vela system has been in operation". If indeed the Ruina panel based their statement on the OJ80 report, then it is misleading in a few respects. Most crucially, it only refers to the total signal duration and not the actual signal shape. And secondly, it assumes a questionable extrapolation to infer equivalency between the AMD and Vela event distributions.

## Reality and/or reliability of the Pioneer AMD single event signals

Early in its mission it was realized that the AMD data conflicted with all other observations that had been obtained of the (micro)meteoroid population of the inner solar system. The Ruina panel failed to mention that such serious questions hung over the AMD single event data set, which had been pointed out in several papers.[20] The objections raised by the authors of these papers included questions over the data reliability (even reality) and the interpretation published by the AMD instrument scientists. They can be encapsulated in the statements within one of them that "no significant fraction of the events reported as real meteoroid events between 1.0 and 3.3 AU is, in fact, due to "cosmic meteoroids," and that "probably between 90 and more than 99 percent of the reported 123 [at that stage] asteroidal events are not real." [21]

Several authors have questioned whether the AMD was detecting anything at all. Whilst eventually concluding that the AMD was responding to a real optical environment, the report by OJ80 on Alert 747 notes that laboratory tests showed that electronic crosstalk could be responsible for the frequent occurrence of nearly identical entrance times for all the sensors. A similar sentiment is expressed in the 2002 Kuiper Prize lecture, where a "high noise level on individual channels" was noted.[22] The instrument scientists stressed that they applied very stringent tests to eliminate noise as a source of their events, but also state that most of the detected events did have a low signal-to-noise ratio.[23]

It is extremely difficult to have any certainty over whether the AMD was detecting real optical signals or only measuring noise and/or spurious (electronically-generated) events. It performed well in its zodiacal light (ZL) mode, as even its critics concede.[24] Further, in its single particle mode it had detected signals from stellar transits through the FOV, as well as particles ejected by Pioneer 10 itself, e.g. after pulsed spacecraft precessions and ejection of a protective cover from another instrument.[25] Presumably these events had much higher signal-to-noise than the unexplained triggers.

The AMD was intended to derive orbital information from the trajectory of a particle through the multiple telescope FOVs. But for all 283 events between 1.0 and 3.5 AU – 232 by Pioneer 10 and 51 by Pioneer 11 – in no case was it possible to determine an orbit. Furthermore, when integrated to predict what would be seen as zodiacal light the result was more than ten times greater than observed in its ZL mode, as well as by the dedicated imaging photopolarimeter (IPP) also aboard Pioneer 10 and earth-based telescopes. This translated into a particle concentration too high by a factor of 50-140 with a best estimate of around 100.[26] Notably this is the same magnitude as the discrepancy between the frequency of events seen by the MDE and AMD referred to in the Ruina panel's report.

These results led the AMD instrument scientists to initially infer that the mechanism behind the triggers was specular glints from specific structural features on interplanetary particles, rather than normal solar light scattering off the entire surface.[27] When converted to size (or mass) the inference was that the AMD had detected particles from several tens of microns up to about 10 cm in size.[28] Specular glints could explain the near simultaneity of the triggers, on at least three telescopes in many instances and sometimes all four, as well as the inability to determine an orbit. Per the proponents they could also explain other anomalies in the AMD single particle mode, such as disparate readings on different telescopes for many events, and signals that dropped below detection threshold and then recovered.

However, this specular glint explanation was also strongly opposed by the community.[29] The existence of such particles had several problems but the primary objection was quite simple, based essentially on the fact that no such characteristic of 'glint inclusions' had ever been found in collected meteorites or inferred for visible asteroids. They would have to be a completely new – and abundant – type of meteoritic or asteroidal body. More technically, they required their ratio of peak to average albedo – the fraction of radiation reflected – to be about 0.01. Since the peak could be taken as around 0.2 then it meant the average albedo was ~ 0.002. Albedo measurements of many collected meteorites of different classes, as well as visible asteroids, had not been observed to be less than about 0.02 for wavelengths of 0.3-1.1 µm and were typically between about 0.05 up to 0.4. Since then, close-up images of comet nuclei, e.g. by the Giotto spacecraft for Halley, have shown them to be quite dark, though still with surface albedos of between 0.02 and 0.05.[30] When heated during their approach towards the Sun the dust ejected via comet jets obviously has a much higher albedo to make their comae so bright in visible light.

Another potential problem with the AMD data set and glint interpretation is that, if it had indeed found a significant population of such large particles, up to 10 cm, then it suggests a non-negligible probability of the spacecraft itself being hit. If not Pioneer 10 or 11, then one of the other fleet of probes – e.g. Voyager 1 and 2, Galileo, Ulysses, New Horizons and many others – to traverse interplanetary space between 1 and 3.5 AU. At a relative velocity of around 15 km/s such a collision would almost certainly be catastrophic.

Following Alert 747, the AMD instrument scientists were probably consulted about their data, as they are mentioned in OJ80. By that stage they had seemingly rejected the 'glint' model and instead proposed that electrostatic forces between the spacecraft and passing particles caused the latter to shatter, resulting in a much-enhanced scattering surface area. However, within a decade they had apparently rejected electrostatic shattering, and instead proposed explosive disintegration of a population of so-called cosmoids.[31]

Cosmoids were postulated to be comprised mainly of volatile molecules, most specifically water (ice), and to essentially be small-scale versions of comets given their similarity in both composition and inferred long-period orbital characteristics. They had a low albedo of 0.02-0.04, consistent with comet nuclei, so were 'dark' and could not be seen until they 'jetted' as comets do on approach to the Sun. Per the authors, cosmoids allowed consistency between the data from all three dust detectors on the Pioneers, namely the AMD, MDE and IPP, and thus dominate the interplanetary dust population.

It would be an understatement to say that the cosmoid hypothesis has been rejected by the interplanetary dust research community, and too time-consuming to go into respective for and against arguments. It suffices to quote from a review article of in situ measurements of cosmic dust, where it is stated "However, since this cosmoid hypothesis is in direct conflict to zodiacal light and in-situ meteoroid measurements, it will not be considered here any further."[32] The subsequent claims by the authors of the cosmoid hypothesis that they could solve a number of outstanding problems in fundamental physics, such as the form of the so-called missing (dark) matter of the Universe, fusion reactions in stars, and the solar neutrino problem, was also viewed with skepticism.[33]

Whilst none of the offered explanations for the AMD data have been borne out, it is notable that at no stage have those who designed, built and operated the AMD invoked a collisional debris scenario. This may be because in many of the events, at least two and sometimes all four detectors triggered simultaneously, which is physically very unlikely. In fact, the cosmoid hypothesis authors note that "Simultaneous entry in all four FOVs occurred in 40 cases; impossible unless the object brightens above threshold after it is in view."[34] The definition here of 'simultaneous' is within 1.6 microseconds. For another 160 events three of the sensors triggered within 3.2 µs, which also implies an unrealistic particle velocity across the ~ 25 cm baseline of the AMD.

Unfortunately, any information on the time difference between the bhangmeter triggers on Vela 6911 for Alert 747 was redacted from the declassified reports. However, a hint may be gleaned from the single particle model of Alert 747 in SSM80,[35] which says that before the bhangmeters trigger, the particle must have reached "a point close to the center of the field of view of both instruments without being detected." This constraint would be independent of whether the detected signal is from collisional debris or the original particle, since it is imposed by the shape, amplitude and overall consistency of the YCA and YVA (the two sensors on-board 6911) first pulse portion of their time histories. So the inferred requirement for the scattering particle(s) to already be in view of the sensors before they trigger is common to both the AMD single event data and Alert 747. This is an important consideration in assessing their ultimate physical origin, which may not necessarily be the same (i.e. obviously, the AMD data did not result from nuclear explosions).

The interplanetary dust community considers the Pioneer AMD individual particle mode data to be unreliable, or perhaps more generously, not understood even to the present day. This can be directly contrasted with data from the MDE impact detector, which continues to be an important part of modeling of the interplanetary dust population (e.g. size distribution, heliocentric distance dependence, dynamics). It is beyond the scope of this paper to attempt to resolve the conundrum of the AMD data. But the ultimate question is whether the AMD was seeing what it was designed to see, namely solar reflection from particulate matter.

It is highly unlikely that the Ruina panel was not aware of the controversies of the AMD data. They may have been influenced by OJ80 who, whilst alluding to its discrepancy with all other data on solar system meteoroids, advise that the AMD data is probably reliable. But OJ80 also state that "VELA observes extremely bright events too often to be attributed to the same mechanism as the Pioneer 10 data" and "we doubt that all of the VELA zoo events can be attributed to the same cause as the Pioneer 10 data". Thus, the Ruina panel should at least have mentioned in their report the controversy over the AMD data, and not used it as evidence to support a case against a nuclear test explanation for Alert 747 without an appropriate caveat.

Since the Pioneers, there have been more probes with dust detection instruments that have traversed interplanetary space, including the Ulysses, Galileo, Cassini and New Horizons missions from the 1990s onwards. There have also been several comet probes, including the Giotto spacecraft fly-by of Halley in 1986. Unfortunately, none of these had a dedicated optical instrument. A component of the Halley probes was a capability to detect the HVI impact flash, but its role was to trigger the primary mass spectrometer component and no data showing optical signatures has been published (to the authors knowledge). Even so, data from these missions is still highly relevant in assessing the Pioneer AMD results and their relation to Vela.

Furthermore, there have been several Earth-orbiting platforms that have specialized dust detecting instruments (e.g. GORID),[36] as well as others with such a capability. Some of the latter include optical instruments, which at least superficially resemble the Vela bhangmeters. Many of these were aimed at the study of lightning, and include the Optical Transient Detector (OTD[37]), Fast On-orbit Recording of Transient Events (FORTE)[38] and Imager of Sprites and Upper Atmospheric Lightning (ISUAL).[39] The cited works consider just lightning data but there would almost certainly be (unexplained) signals from other sources. Of course, following the Vela satellites there have many more actual bhangmeters orbited, especially on the GPS constellation of satellites, and perhaps others, e.g. the Defense Meteorological Satellite Program (DMSP).[40]

## New and relevant data sets from GPS Bhangmeters and other optical detectors

It is plausible that data would now exist that could be further compared to the Alert 747 bhangmeter recording and/or the Vela zoo. Both OJ80 and SSM80 made the point that the best data set to compare to Alert 747 is the Vela zoo itself, and lamented the fact that there were insufficient events to perform a rigorous statistical treatment. OJ80 concluded that “the only truly relevant database is that produced by the Vela spacecraft, and that whatever the physical cause of each event, this substantial body of observations contains a description of the spacecraft environment as it is viewed by the optical sensors”. SSM80 suggested a history of $10^2$ to $10^6$ multiple pulse events with nuclear-like rise to first maximum, but of obviously non-nuclear origin, would be required to credit a single-object model. Can the sample size be increased?

Consisting of around 100 members, the Vela zoo was a sparsely populated sample as of about mid-1980 when various bodies were producing their reports on Alert 747. Furthermore, as seen in Figure 3 it seemed that there were at least two physical mechanisms at work producing their light curves, one being reflection off passing meteoroids (OJ80) and the other being unexplained but possibly a result of a meteoroid collision with the satellite. Beyond Alert 747 the Vela system continued operating for another 5 years, when on 27 September 1984 the still-working last satellite (6909) was deliberately switched off.[41] So the Vela zoo-on sample would have increased by perhaps a few tens of events.

But since then many more bhangmeters have been placed into orbit on various satellite systems. The most well known is the Global Positioning System fleet (GPS).[42] The first GPS satellite was launched in February 1978, there have been about 50 such satellites orbited, and as of November 2014 there were 31 operational units. As far as can be told from pictures of at least one version of the system a satellite contains a single bhangmeter. This would make sense as the system is designed to have in-built redundancy, such that between 4 and 8 satellites have overlapping fields of view. Another system is the Defense Support Program (DSP) satellites, with 23 units launched since 1970, and with 5 currently operational (as of July 2014). Optical data from these are routinely published as light curves for bolides entering Earth’s atmosphere.[43]

Both the GPS and DSP satellites are in relatively high orbits, around 20000 km for GPS and 36000 km (geosynchronous) for DSP. Also equipped with optical detectors, but in much lower orbits (i.e. less than 1000 km), are the OTD, FORTE and ISUAL systems previously mentioned, and perhaps others. Thus, over the last almost 40 years there have been nearly 80 satellites equipped either with bhangmeters or related optical sensors to detect transient, ultra-fast signals. One source says that the rate of unexplained signals is around 6.76 per year per satellite.[44] Assuming a platform lifetime of around 10 years then the number of events is in the several thousand. By now the population of unexplained signals would have grown significantly, into the thousands, offering a much larger sample for a robust statistical study of the frequency of such detections, their amplitudes, shapes (e.g. number of pulses and relative timings) and total durations.

Such a study could greatly assist an assessment of the uniqueness or otherwise of Alert 747. An obvious question to ask is whether any other signal since 22 September 1979 has the properties of a nuclear explosion, inclusive of rise-time, double pulse, internally consistent times of maxima and minima (i.e. giving the same inferred yield), total duration and amplitude. Based on the Vela experience, and assuming Alert 747 was non-nuclear and a zoo member, another 10 or more such signals might be expected (as 747 was inferred by Ru80 to be one of a hundred or so zoo-ons). To the author's knowledge no reports of such signals have been made.

But as always there are caveats. For instance, given the different orbits of Vela and all the other systems they will be subject to a different micrometeoroid environment, certainly in terms of flux but plausibly other parameters like velocity and/or size. Further, all the systems will be different in their geometrical design and/or placement of the optical sensors with respect to other spacecraft structures. This too could influence the form of the signals generated by micrometeoroid collisions.

## Could a bolide airburst be the origin of Alert 747?

Qualitatively a bolide could at first be thought of as a possible explanation for Alert 747, as the effect of its atmospheric entry does in several ways resemble that of an airburst nuclear explosion. Indeed, their energy release is often expressed in kilotons, and as well as visible light and infrared radiation they also produce a large infrasound signal. If sufficiently energetic, and/or if one or more fragments hit the ocean surface, a hydroacoustic signal may even be generated.

In February 1981 reports appeared in the international media that another satellite had detected a signal on 16 December 1980 over approximately the same region as inferred for Alert 747.[45] It was not a Vela detection, but instead reported to have been an infrared signature collected by another satellite system. Controversy over whether it was a possible atmospheric nuclear test did not last long however, and consensus seems to have been quickly reached by various agencies that a meteorite entering and burning up in the Earth’s atmosphere was responsible for the signature.

There are several reasons why a bolide cannot be the origin of Alert 747. The main objection is the signal shape. As observed from space-based platforms, no bolide entry has a light curve – let alone such a short initial pulse – anywhere like that of a nuclear airburst.[46] They typically have a duration longer than a second and/or multiple (≥ 2) bright peaks of approximately equal duration, and/or have significant sub-structure within the peak(s). Also, given the energy release typically occurs at an altitude of a few tens of kilometers then both its optical and infrared signatures are highly unlikely to be obscured by cloud. Presumably then other satellites would have detected the event, as it was such cloud cover that was suggested to explain the absence of Alert 747 detection by other platforms (assuming their field-of-view overlapped with the event location).

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