SIDE EFFECTS OF SPACE DEBRIS ON ASTRONOMICAL OBSERVATION

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INTRODUCTION

Astronomical research continues to use ground-based facilities as a principal means of gathering data. The optical light buckets which are trained each night on celestial sources have historically had to just contend with natural interference. Sunlight, moonlight, clouds, debris created by volcanic eruptions, atmospheric seeing, and aurora are examples of factors which modify the interception and analysis of energy radiated in the optical spectrum and received at the collector end. In the last 5 years the "unnatural" encounters with artificial earth satellites are making themselves more pronounced and have become the subject of this limited study.

We researched an earlier phenomenon which became known as the Perseus (or Aries) Flasher (1) with a conventional low light level television system which surveyed a suspected emission zone in the sky. After negative results were achieved, and other reports of bright flashes seemed to produce the hint that the emissions did not occur at the precise same location each time, we began to look at other possibilities for the origin(s).

We have been analyzing optical (visual) signatures of Soviet spacecraft for a number of years. Bright flashes of short (less than one second) duration have been characteristic of some satellites over the course of a typical pass. These ranged in nature from a lone specular burst reaching naked eye brightness to those which are beamed preferentially on a periodic basis from flat surfaces on spinning bodies. Once an object attains this mode it can usually be ascribed to lack of altitude control and hence falls into the category of space debris.

In our initial analysis of some of the events related to the Aries Flasher reports we found direct correlation with passages of sunlit earth satellites through the region (within the provided error boxes) for a significant fraction of reported events (2). The question then became: were flashes like these important in terms of their effects on astronomical research programs? Were there other situations in which satellite passages affected or continue to impact data collection? We present here a review of our current work, most of which is still in progress.

CHILEAN GAMMA RAY STUDY

Since flashes by themselves are not a natural by-product of regular

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observational studies, we found that one project to search for visible energy emissions from gamma ray sources kept records that could be used for our analysis. A series of intrusions into the fields of view of two instruments, one at Cerro Tololo Interamerican Observatory (CTIO) and the other at the European Southern Observatory (ESO) in Chile 101 km away were compiled and presented in the literature (3). The investigators attempted to link the shapes of the light curves derived from these intersections to either meteor or satellite signatures, without being able to directly verify the true nature of the passage.

We considered a total of 63 reported events and attempted to find positive intersections with passing sunlit spacecraft. These would include active payloads, spent rocket casings, and cataloged debris for which orbital elements were available. The results of this investigation are shown in Table I.

We approached the problem from two directions. First we attempted to analyze Cases E1 through E14 from the Pedersen et al. study of N49 (4). However, we found that most of the cases could not be processed due to lack of a consistent and complete satellite data base for those time frames. Next, rather than analyze the test field from Schaefer et al. we pointed the telescope at N49 as if it were a random field, at the same time as the Schaefer group's observations to determine whether we could arbitrarily detect satellite coincidences.

TABLE I CASE DATA

DOY	CASE	DATE	UT	HA	H	AZ	1E	2E	1A	2A	S	C	D	
(TARGET FIELD = N49)														
283	E1	10/09/83	0747	E0107.4	51.6	169.2	49	55	166	173	S	1	1	
286	E2	10/12/83	0511	E0332.0	41.2	154.7	38	44	151	157	S	0		
301	E3	10/27/83	0128	W1743.5	-	-	-	-	-	-	-	-	-	*
336	E4	12/01/83	0246	E0240.3	45.7	158.2	42	49	155	161	S	1		
338	E5	12/03/83	0453	E0025.1	52.8	175.8	49	56	172	178	S	0	-	
342	E6	12/07/83	0525	W0022.8	52.8	183.8	49	56	180	186	S	-	-	*
359	E7	12/24/83	0259	E0056.6	52.0	170.8	49	56	167	173	S	-	-	*
365	E8	12/30/83	0321	E0010.9	53.0	178.2	49	56	175	181	S	-	-	*
9	E9	01/09/84	0539	10244.0	45.4	202.1	42	48	199	205	S	-	-	*
22	E10	01/22/84	0146	E0018.4	52.9	176.9	50	56	173	180	S	-	-	*
25	E11	01/25/84	0205	W0012.5	52.9	182.1	50	56	179	185	S	-	-	*
30	E12	01/30/84	0320	W0147.4	49.5	196.3	46	52	193	199	-	-	-	*
31	E13	01/31/84	0840	W0712.2	19.8	204.0	17	23	201	207	S	-	-	*
39	E14	02/08/84	0742	W0646.6	22.1	205.2	19	25	202	208	-	-	-	*

(TARGET FIELD = N49 random sample)

232	E15	08/20/85	0159	W1342.6	7.4	169.8	3	11	166	174	1	-
233	E16	08/21/85	0832	E0339.4	40.6	154.2	36	45	150	158	2	-
239	E17	08/27/85	0219	W1430.2	9.6	165.5	5	14	161	169	2	-
239	E18	08/27/85	0331	W1542.4	14.3	159.9	10	18	156	164	0	-
240	E19	08/28/85	0146	W1401.1	8.2	168.1	4	12	164	172	3	-
240	E20	08/28/85	0930	E0213.7	47.8	160.7	45	51	157	164	0	-
241	E21	08/29/85	0157	W1416.0	9.0	166.8	6	12	163	170	4	-
245	E22	09/02/85	0124	W1358.7	8.2	168.4	5	11	165	171	5	-
245	E23	09/02/85	2355	W1233.4	5.6	176.6	2	9	172	180	20	-
246	E24	09/03/85	0153	W1431.7	9.7	165.4	6	14	161	169	2	-
246	E25	09/03/85	0810	E0310.2	43.2	155.8	39	47	152	160	2	-
247	E26	09/04/85	0843	E0233.2	46.3	158.8	43	49	155	162	0	-
248	E27	09/05/85	0035	W1321.4	6.7	171.9	3	11	168	176	9	-
248	E28	09/05/85	0324	W1610.9	16.6	158.0	12	21	154	162	2	-
248	E29	09/05/85	2344	W1234.2	5.8	176.2	3	9	173	179	8	-
249	E30	09/06/85	0202	W1452.6	10.9	163.6	7	15	160	168	3	-
231	C31	08/19/85	0450	W1629.7	19.0	156.7	16	22	153	161	0	-
231	C32	08/19/85	0557	W1736.9	25.1	153.6	22	28	150	158	0	-
232	C33	08/20/85	0218	W1410.3	9.1	168.1	6	12	164	172	1	-
232	C34	08/20/85	0913	E0302.6	44.8	156.0	42	48	152	160	2	-
232	C35	08/20/85	0938	E0237.5	46.9	158.0	44	50	154	162	1	-
233	C36	08/21/85	0651	E0521.0	31.2	152.2	28	34	148	156	0	-
234	C37	08/22/85	0233	W1424.2	10.1	166.0	7	13	162	170	5	-
234	C38	08/22/85	0543	W1734.7	24.9	153.7	22	28	150	158	0	-
234	C39	08/22/85	0735	E0433.0	36.1	152.3	33	39	148	156	2	-
234	C40	08/22/85	0934	E0233.7	47.2	158.3	44	50	154	162	4	-
239	C41	08/27/85	0018	W1228.5	6.5	177.1	3	10	173	181	6	-
240	C42	08/28/85	0027	W1241.5	6.6	175.8	3	10	172	180	3	-
240	C43	08/28/85	0048	W1302.6	7.1	173.7	5	10	170	178	9	1
240	C44	08/28/85	0606	W1821.4	29.5	152.5	26	33	149	157	0	-
240	C45	08/28/85	0715	E0429.2	36.5	152.4	33	40	149	157	0	-
240	C46	08/28/85	1008	E0135.9	51.1	164.8	48	54	161	169	1	1
241	C47	08/29/85	0022	W1240.4	6.6	175.9	3	10	172	180	17	-
241	C48	08/29/85	0622	E0518.6	31.5	152.2	28	35	148	156	1	-
241	C49	08/29/85	0917	E0223.1	48.0	159.3	45	51	156	164	1	-
242	C50	08/30/85	0321	W1543.9	15.3	159.7	12	19	156	164	1	-
243	C51	08/31/85	0721	E0411.5	38.2	152.7	35	41	149	157	0	-
244	C52	09/01/85	0558	W1829.2	30.2	152.3	27	33	149	157	0	-
244	C53	09/01/85	0625	E0503.7	33.0	152.1	30	36	148	156	1	-
247	C54	09/04/85	0119	W1401.2	9.1	168.1	6	12	164	172	5	-
247	C55	09/04/85	0126	W1408.3	9.4	167.4	6	13	163	171	8	-
248	C56	09/05/85	0532	W1818.9	29.2	152.5	26	32	148	156	0	-
248	C57	09/05/85	0916	E0156.5	49.9	162.2	47	53	158	166	2	-
248	C58	09/05/85	0943	0129.4	51.2	165.7	48	55	162	170	3	-
249	C59	09/06/85	0109	W1359.1	9.0	168.3	6	12	165	171	0	-
249	C60	09/06/85	0326	W1616.5	17.9	157.5	15	21	153	161	0	-

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249	C61	09/06/85	0337	W1627.5	18.8	156.9	15	23	153	161		1	-
249	C62	09/06/85	0339	W1629.5	19.0	156.8	15	23	153	161		1	-
249	C63	09/06/85	0422	W1712.6	22.8	154.6	20	26	151	158		0	-

Legend:
DOY = day of year when observation was made.
CASE = case designator, where E indicates ESO site and C indicates the CTIO site.
DATE = date of observation.
UT = time of observation in Universal Time (hours, minutes)
HA = local hour angle where W indicates west, E indicates east
H = elevation of N49
AZ = azimuth of N49
1E = lower limit of elevation scan
2E = upper limit of elevation scan
1A = lower limit of azimuth scan
2A = upper limit of azimuth scan
S = event suspected to be caused by satellite intrusion
C = number of satellites found within 3 degrees of position and 2 minutes of time
D = number of satellites found within 15 arc-minutes and 1 minute of time
* = case not completely analyzed

Thirty of the reported flashes seen by the Pedersen and Schaefer Groups were within the 6.5 arcminute field of the 28 cm aperture telescope at ESO, and 33 intersected the 6.62 arcminute field of the 0.61 m instrument at CTIO. Those events labeled as "S" were suspected to be caused by artificial earth satellites. None of the intrusions were simultaneously observed in both telescopes, which might be the case if they were of geostationary origin.

METHOD OF ANALYSIS

A software program called SATRAK was run on a VAX 11/785 computer system at the NASA/Johnson Space Center. Each set of computations absorbed 45 minutes of CPU time and produced a pattern of intersections within a + or - 2 minute time window centered on the reported event. The position of the gamma ray source was recalculated in elevation and azimuth from the respective site every time a new event occurred.

First, a three degree radial search pattern was formed about the gamma ray source N49 (R.A. 05h 26m Dec. -66.15, 1950.0). Element sets for all artificial satellites available to us from NORAD were accessed each month for every observation window. Separate files were built with epochs chosen as close to the time of intrusion as possible. Propagation of mean classical elements over time increases the likelihood of incorrect analysis. However, due to historical element files only being available once each 30 days, a given set was propagated up to 12 days in the worst case. A second detailed window was constructed for satellites passing within 15 arcminutes of N49 and within 60 seconds from the reported

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time.

RESULTS

In our previous analysis of the Aries Flasher outbursts, we were able to obtain orbital elements whose ages were less than 3 days and only required short propagation; the reported flash positions were grossly in error (valid to + or - 3 to 5 degrees). For the Chilean observations, the reverse was true. The event position was known to within several arcminutes, but the ability to pinpoint each spacecraft was partly compromised by delays or accelerations due to atmospheric drag, age of elements, and propagation errors.

Of cases E1 through E4, only 4 of these could be effectively processed. Two encountered a sunlit satellite within 3 degrees of the position and only one found a direct intersection with the smaller 15 arcminute target. It is important to note that we directed our computer search at N49 even though the Schaefer group simultaneously sampled a separate test field near the south celestial pole for 49 other cases (E15 - C63). We found that a sunlit satellite crossed through our field of view 75% of the time using a 3 degree radial search pattern.

Only two intersects occurred in the smaller target zone. From these results we can say that viewing a sizable arbitrary field 6 degrees in diameter at varied times of night will likely result in some satellite intersecting it on a random basis. The smaller the target area, the less likely it is to detect a random satellite. Just because an object intersects the field does not automatically imply that a detectable flash will be produced.

The short dwell time within the field of view would likely preclude very large overall variations in magnitude from appearing in the light curve. Thus the Schaefer group's technique of classifying satellite passages via symmetric, flat-topped light curves may well be a valid indicator. It would be interesting to see the response of ESO detectors to a control group of known satellites, each having a different rotation rate.

Prediction accuracy is not normally reliable enough to calculate to within 6 arcminutes (field of view) for many spacecraft using this retrospective technique. Propagation of element sets either forward or backward in time extended anywhere from as little as 1 to as many as 15 days. Over the longer time periods, the degree of accuracy of most sets of orbital elements (in particular the value of the first derivative of the mean motion), the element set aging process, and the ability of the software to uniformly propagate, impacted the results. We would consider it a very fortunate occurrence to find an exact agreement for even one case under these circumstances.

Future work includes processing as many of the Schaefer group cases as possible to ascertain the coincidence of sunlit satellites with their test field. Because there are an unknown number of fragments in orbit which cannot be tracked due to their size distribution, we expect that correlating many other types of flashes with the cataloged satellite data base may prove inconclusive. Ground radar sensing limitations currently restrict the population of trackable satellite material to those with radar cross sections larger than about 10 cm (5).

THE ODESSA GAMMA RAY STUDY

Moskalenko et al. (6) have studied the Odessa observatory astrographic plate collection with the intent of detecting evidence of gamma ray burst phenomena in the optical spectrum. Very wide field cameras were used at the astronomical observatory of the Odessa State University in the USSR and exposed for 30 minutes each. After surveying 22,000 plates one flash appeared on two overlapping field plates exposed on October 20, 1959, in the zone of the source GB 791101. The source, located at R.A. 19h 38m 24s and Dec. +38.1 degrees (1950.0), has a flash of approximate visual magnitude +13.1. Because of the double coincidence of the flash appearing simultaneously on two separate camera plates (colocated geographically) we must consider this as a high priority for investigation.

Moskalenko et al. consider the likelihood of artificial earth satellite intrusions as a cause but immediately rule it out. We have reviewed the space population as of that date and find only 8 satellites in orbit at that time which would have been visible even from Odessa. Orbital element records from that period are being researched for later analysis. However, we agree that the probability of a sunlit satellite being the culprit must be almost nil, and should probably be disregarded.

Moskalenko also recounts 8 other events which are single, unconfirmed flashes (7). The three most recent ones occurred on July 15, 1980, December 28, 1986, and November 21, 1987. Each was found at a different set of celestial coordinates. The 1986 occurrence was the most prominent at visual magnitude +4.5. Analysis of these observations is pending location of complete element histories.

A FLASHING SATELLITE GROUP

During 1986-1987 we found that certain members of an orbiting earth satellite group had a tendency to produce naked eye flashes of considerable consequence. These objects have been classed (8) as part of a Soviet electronic intelligence program which is apportioned into two subtypes. The first is a group called the "heavy ELINTs" which are an earlier generation of satellites. It was followed in development by the second group known simply as ELINTS. These objects have the following characteristics:

Inclination: 81.2 and 82.5 degrees
Apogee: 660 km
Perigee: 630 km

While active on orbit, the satellite will usually give the appearance of a non-variant object of absolute magnitude 6.0. After accomplishing its mission, the stability of the spacecraft will sometimes change. At least one flat surface will produce brilliant naked eye flashes (for some members) on a preferential basis at some point along a typical sunlit arc. Some of the flashes are repetitive, while others are not.

Five out of 34 heavy ELINT satellites (14%) and 9 out of 26 (27%) regular ELINTs exhibited the flash characteristics. The rest either remained more or less non-variant or transitioned into a state somewhere between the steady state and the flash state where gradual rises and falls predominated over the light curves.

Both types of ELINTS seem to be similar in overall surface area if we can presume that reflectivity is a true measure of size. Figures 1 and 2 display the absolute magnitudes of the class members observed; they bear a close resemblance to one another. Also the radar cross section (RCS) values for the heavy and regular classes have been shown to be similar (9).

One interesting phenomenon was observed from the ELINT Cosmos 1726. This object has been watched for over 12 months during consecutive favorable visibility windows. Depending on the phase angle subtended by the observer, sun, and reflecting surfaces from the satellite, glints are given off only in a certain part of the sky. These sky sectors most likely to beam flashes are approximately 20 degrees in width (for this one satellite at our latitude of 29.5 degrees north). While it was first suspected that this might have been a simple artifact, the phenomenon was reproduced on 3 occasions over a year for evening passes, and on 2 other times for morning passes. Intervals between flashes were about 8 seconds. Each flash ranged from +2 to -1 visual magnitude in brilliance. After the glint state was passed, the peaks degenerated into pulses and then finally into gradual maxima and minima. This was symptomatic of rotating surface areas sending mirror-like beams; then the viewing angle shifted to create a more unfavorable reception with the passage of time. Because of the consistency of their appearance we suspect that once becoming inactive, each spacecraft is left to spin in a set attitude which is maintained over time. We describe this family as a reference group of satellites capable of beaming flashes of much greater intensity than those described by the Chilean cases.

NEW STARS OR SATELLITES?

Photographic observation from Japan on November 22, 1986, led to the initial announcement of the discovery of Nova Lacerta 1986 (10). This new star's existence was never verified visually, but was claimed based on a starlike image contained on a photograph taken at 1019 GMT on that date. We researched this report with the satellite data base for that period and did not find a positive correlation. The reported celestial position R.A. 22h 22m, Dec. +48.2 (1950.0) is not commensurate with geostationary satellites and it is unlikely that a moving (i.e. non-geostationary) spacecraft would have appeared as a point source on such a photograph. At that time of night the position was in an area deep in the earth's shadow. Since the "nova" was never officially confirmed, the question to ask is whether a satellite glint might have been the cause. Our analysis does not support such a contention.

Another "new star" was reported visible for the period between 2135 and 2143 GMT on April 18, 1987 as seen from Luneburg, West Germany. The object was located at R.A. 13h 43m, Dec. -1.85 (1950.0) peaking at visual magnitude 4.6 (11). We analyzed this satellite against the spacecraft data base and found no absolute correlation to a known satellite. However, two points stand out that logically infer a geostationary satellite cause. First, the "new star" appeared to maintain its position in the sky while stars nearby moved past at the sidereal rate. Second, the observed declination was coincident with the expected declination of a geostationary spacecraft. A third characteristic was the slow variation in brightness culminating in a very bright peak, then sinking back out of sight. This is symptomatic of an inactive satellite or debris. The information data base used does not contain objects that are either too small to be tracked or those which have been lost by the NORAD network. During the observation window at Luneburg, there were at least 5 known geostationary spacecraft illuminated within 3 degrees on either side of the new star location.

D. L. Welch recounts a one-second duration optical flash using the Canada-France-Hawaii Telescope on January 21, 1987 at 1134 GMT (12). We have carefully reviewed the case of the 13th magnitude flash and have found no coincidence with the artificial earth satellite population. In fact, the nearest sunlit spacecraft was more than 5 degrees away and passed by one hour earlier.

S. Korth reported a similar one-second duration flash of magnitude 13.4 while viewing the dwarf nova IR Geminorum on March 8, 1988 at 2024 GMT from Monheim, FRG (13). This event is currently awaiting analysis.

Observation made by D. Talent using the KPNO 2.1 meter telescope with an 8.6 arcsecond field of view found a 13.6 magnitude object on September 26, 1981 at 1132 GMT (14). Moving at a rate of 17.3 arcseconds per second, it was tracked 240 seconds with an intensified image dissector scanner and revealed a classic solar spectrum. We note that this object is also in the analysis queue but is most likely a satellite

PHOTOGRAPHIC TESTS

A photograph obtained from Trieste, Italy, showed what appears to be another satellite glint phenomenon (15). However, lack of information on the specific location and time of observation has made it impossible so far to investigate this event. The apparent magnitude seemed to be around +2. The facet of magnitude estimation based on photographs is of some curiosity.

At the very first, we considered the apparent visual magnitude based on comparison to stellar images impressed on the same photographic frame to be directly correlatable. We have conducted simulations, first to try to duplicate the conditions under which an earlier photo was made (16). We photographed a reference satellite, Cosmos 1726, known to produce flashes up to -1 visual magnitude during opportune moments from sites in (Paris) France, (Jerusalem) Israel, and (Houston) Texas during 1987. Flashes were observed ranging from +2 to -1 but failed to record on ASA 400 TRI-X film with a 50 mm f/1.8 lens. The intensity of sub-second specular flashes must be much brighter than initially thought, in order for the chemical reactions in the emulsion to be triggered. We presume that the human eye underestimates the apparent visual magnitude for these events by at least 2 magnitudes, no doubt due to the eye-brain response mechanism. This assertion was confirmed by observing and photographing aircraft strobe lights at night under similar conditions.

IS THERE A PROBLEM?

The cases we have cited which are in work are the most significant body of evidence where satellite intrusions have produced side effects on astronomical observation efforts. Our initial analysis of the likelihood of randomly encountering a satellite within a fairly large field of view shows that sunlit debris will be found on a high frequency basis. Yet the number of reported instances are quite low where a study has been compromised by their presence.

One very pronounced effect which we have experienced in studying satellites in general is the overpopulation of certain inclination orbits. The tendency to spot two satellites in the same 5 degree field of view, moving in the same direction simultaneously, with similar angular velocities has increased over the years. The 81 to 83 degree inclination zone is where we have observed this phenomenon to be most prevalent. In other bizarre coincidental observations two satellites would be spotted moving in opposing directions at the same time in the same field, also in this polar inclination regime.

While NASA recognizes space debris as an imminent collision hazard we think that there does not appear to be substantial evidence to warrant a state of alarm, at least in terms of immediate effects on earth-based observations (17). Widespread claims of contaminated data do not appear in the literature. Satellite trails are quite often reported to be found on wide field Schmidt camera plates/films that are employed in comet or asteroid studies. These unwanted guests appear to be more of an annoyance than an arbiter of serious research.

An impact to the Hubble Space Telescope (HST) however, seems to be of concern due to its space looking mode of operation from a perch 320 nautical miles above the surface of the earth. It has been calculated that a sunlit satellite greater than 1 meter in radar cross-sectional area would be viewed by the Wide Field Camera once each 2 hours (18). Objects smaller than this size are estimated to intercede into its field of view on the order of once every 20 minutes. Not only do such passages offer the possibility of guiding interruption, but also could be a potential threat to the health and well-being of the fine guidance sensors.

The problem, if one exists, should be somewhat biased toward programs conducted in the northern hemisphere. This is due to apogees of highly elliptical satellites and attendant pieces being clustered preferentially at 36,000 km heights at high declinations. Under normal circumstances the two hours following evening astronomical twilight and preceding morning astronomical twilight should offer the most interference from satellites in orbits below 1600 km. During certain situations seasonal solar illumination causes the earth's shadow to be oriented so that interference is more pronounced based on latitude of the observing site. The distant apogees of Soviet Molniya and some Cosmos satellites create capacity for incursions at nearly any hour of the night in many parts of the sky as seen from mid to high northern latitudes.

The future buildup of debris and failure to find a practical method to remove it from the near-earth environment will no doubt increase the frequency of encounters between narrow field detectors and illuminated satellites. While it is not practical to attend each instrument to ascertain the source of interference, it will be incumbent on the investigator to discriminate the problem. Only if enough data is taken, would a technique involving light curve classification (Schaefer et al.) be useful in segregating meteors, aircraft, atmospheric variation and space debris from "real" data; yet in many projects where observing resources are severely constrained, this becomes impractical.

RECOMMENDATIONS

We recommend that observations of flashes be logged judiciously for application to future investigations. Though it may be tempting to ascribe a flash to an artificial earth satellite encounter, we caution against assuming this very convenient posture for every case. There indeed may be astrophysical rationale for continuing to study flash phenomena in an orderly fashion. For this to proceed we encourage that flash events be carefully documented in the literature and include such pertinent parameters as the precise latitude, longitude, and altitude of the site.

Photographic exposures using such devices as twin astrographs where simultaneous images are obtained of the same field at the same time from the same location are not absolute indicators of a flash from outside the earth's atmosphere. We suggest a procedural change to take simultaneous photos from stations separated by one or more kilometers in order to reveal separation of flash images for near-earth sources. Both satellite reflections and aircraft lights may contribute to false stellar images in the present observatory collections of photographic plates. With colocated twin astrographs, distinguishing near-earth from far-earth sources could be extremely difficult, if not impossible.

We also recommend that standard procedures be adopted for the processing and safe archival of photographic plates that would be used in analysis in order to minimize the likelihood of image defects or degradation.

A final suggestion is for the space tracking community concerned with the growing population of artificial satellites. Historical files should be developed at least monthly and maintained on a permanent basis. Presently available orbital element files are non-contiguous--a fact which has hampered our research project.

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