THE HAZARD TO ASTRONOMY FROM OPERATIONAL SATELLITES

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ABSTRACT. Operations in space are frequently regarded as not creating problems because of a presumed large volume dilution factor. That this is not the case is clear from the threat posed by space debris to operational space craft. However, the problems posed by space activity also impinge directly on astronomy through the crossing of fields under observation, optically and in the IR, by both bright satellites and debris. Telecommunications with operational satellites are having a grave, even potentially disastrous, effect on radio astronomy and the recent development of inter-satellite and satellite-to-ground communications using far red laser beams has the potential to bring the same threat now affecting radio astronomy to optical and IR astronomy.

1. Introduction

The science of astronomy is under significant threat from many activities of a civilised society. These activities produce unwanted degradation of observational astronomy - upon which the whole of astronomy depends for its primary data. Astronomy, unlike any other physical science - apart from seismology - is obliged to “share” its “laboratory” with the rest of mankind. The rest of mankind, being unaware they are in someone’s laboratory, create mayhem. The consequences for astronomy of electromagnetic noise at all wavelengths is all too readily documented (Crawford 1989, McNally 1994, this volume, for example). This paper is designed to draw attention to another hazard consequent upon the activities of the rest of mankind - the consequences of the increasing population of operational satellites and associated large debris (non-operational satellites, fuel tanks, rocket motors, etc,.

2. Plate Trailing

Deep sky surveys have brought to light just how common plate trailing has become. The first Palomar Survey rejected plates which carried trails. Now, however, recent deep sky surveys accept plates which carry many trails. Analysis of the counts by Tritton and Norton (1995) of UK Schmidt Plates and analysis of recent SRC/ESO Survey Plates show that 50% of all the plates investigated carry at least one trail and 25% carry’ multiple trails. In one instance a single $6^\circ \times 6^\circ$plate carried 13 trails. As the counts were carried out with only modest optical aid, there are likely to be fainter unnoticed trails.

Conventionally such trails are put down as ”space debris trails”. The nature of the debris is not determined.

The work of Tritton and Norton showed that a steep increase in debris trail rates occurred between 1983/84 and 1985/86. As no super break-up had occurred in that interval, enquiry showed that a filter change had occurred at that time. The data since 1985/86 to 1993/94 was treated as a homogenous sample to compare with the population of satellites for the same period. The data were normalised to the values for 1987/88 to create an appropriate index I_{trail} or $I_{satellite}$ - the values are given in Table I (see McNally & Rast 1998).

Tab. I

Year	Trails/60min exposure	no. of satellites in orbit	I_{trail}	$I_{satellite}$
1985	2.5	1500	1.1	0.9
1987	2.3	1624	1.0	1.0
1989	2.7	1749	1.2	1.1
1991	2.4	1916	1.0	1.2
1993	2.9	2084	1.3	1.3

The satellite numbers are taken from Fig.1-2, p.20 of Orbital Debris (National Research Council, 1995) and the trail data came from the UK Schmidt archive as determined by Tritton and Norton. The satellite index $I_{satellite}$ increases steadily while the I_{trail} increases rather jerkily. This is to be expected since the distribution of plate observation times will vary from year to year. However, it is clear that within such limits, the indices are rising in step. This would support the view that the debris responsible for "debris trailing" are satellites and no doubt large pieces of debris capable of reflecting significant amounts of sunlight. There seems to be no evidence that trail rates are influenced by major satellite break-ups. 20% of all the 8000 + catalogued space debris (McNally & Rast 1998) are at the limit of naked eye brightness. The double satellite TiPS (with an angular size of $\sim 7'$ in the sky) is again just on the edge of naked eye visibility.

Satellites (and their associated fuel tanks, etc.) double in number approximately every 15 years. Since a satellite must be illuminated by the Sun in order to reflect sufficient light to record a trail, trailing is going to be most frequent near twilight. Since Schmidt plates are exposed from shortly beyond twilight and through the hours of darkness, it follows that trailing will increase more slowly than the population of operational and non-operational satellites. But the launch rate of satellites is undergoing rapid acceleration with the development of multisatellite communications systems such as IRIDIUM and TELEDESIC. IRIDIUM is now operational and well on the way to an operational system of 66 satellites plus a number of backup satellites. Given that the operational lifetime of each component satellite is expected to be three years, it is clear that IRIDIUM will quickly generate many more satellites than the operational 66 + standbys. The early plans for TELEDESIC called for in excess of 800 operational satellites and clearly that system would lead to a virtual doubling of the current number of satellites very quickly. The revised plans stilI call for in excess of 200 operational satellites. Given that there is no reduction in the numbers of satellites being launched for other purposes, we may expect a significant increase over the next few years in the number of operational satellites - and a concomitant rise in the number of trails across astronomical fields under observation.

3. Consequences for Astronomy

The consequences for astronomy are only too clear. Few deep sky survey plates will be trail free and more plates will carry multiple trails. Photometric observations will increasingly be affected by trailing.

A plate is not necessarily ruined by carrying trails. The trails may not affect those areas of the plate of maximum interest. Nevertheless any trail degrades the plate. The prospect of an enhanced trail rate is not good news.

It is not only deep sky photographic surveys which are affected. One might expect considerable trailing for plate scales of $6°\times 6°$. However, photometric fields (with fields of 30" x 30") are also increasingly affected. There are examples where a piece of debris crossing a photometric field has been originally interpreted as the optical equivalent of an γ-ray burster. Because photometry is carried out on objects of all types from bright to exceedingly faint, it is clear that photometry must also be concerned with not only large space debris but with smaller and therefore fainter items of space debris. Photometric fields may be small but debris populations increase as the size of the debris decreases. The most sensitive photometric detectors are fitted with shutters designed to close if too bright an object is likely to enter the field. However, one might anticipate an unfortunate series of mishaps, which might allow damage to a sensitive detector as well as loss of observations.

4. Remedies

One might argue that there is an obvious remedy - to avoid trailing wait a decent interval following sunset and before sunrise, so that the amounts of light reflected by satellites will be negligible. This period is conventionally set at two hours, i.e. four hours out of any given night. This represents a very significant fraction of a night. For example, four hours is 40% of a 10 hour dark period. This is a serious inroad on observing time given that the deepest surveys and serious photometry must avoid the bright of the Moon. In other words the operational efficiency of a telescope is reduced and concomitantly the hourly cost of operation is increased, the more hours a telescope remains idle. That extra cost is a charge on the science of astronomy and not on the owners and operators of satellites. This is interference by one party on the legitimate activities of another. Remedy however is not simple.

Clearly if it is important to avoid trailing particular observations, then the hours of maximum trailing should be avoided. However, as McNally & Rast (1998) have shown, the orbits of over 8000 items of space debris are known and kept updated - the expected incidence of trailing can be predicted and observing programmes scheduled accordingly. The process may not be as extensive as including all 8000 odd catalogued space debris, but only that subsection deemed capable of affecting the planned observations. Such forward scheduling could reduce trailing in the post- and pre-twilight periods.

Satellites could also be made less reflective. This is an area which still requires investigation. Clearly poorly reflecting satellites will preclude optical detection of these satellites. Large debris from collisions will not necessarily retain the low reflection properties of their parent bodies but low reflection satellites would again help reduce the numbers of recorded debris trails.

This is an area where activity in one field has impact on activity in another. Exploitation of space is a legitimate activity. It is an area of activity of benefit to astronomer and non-astronomer alike. Astronomers as citizens benefit from first class, state of the art, communications facilities. Astronomers as astronomers benefit from access to space observatories. But space activity impacts astronomical observation - another legitimate activity. This is an area where close co-operation with the space agencies could be of great benefit to astronomy though at some expense to those agencies as well as astronomy.

5. A Space Nightmare

There is a further space problem which keeps recurring - the prospect of advertising from space. This is perhaps one of the most worrying problems for optical astronomy. The Moon rules out observation of the faintest celestial objects for about two weeks of each lunation. Space advertising would need to rival the full Moon in brightness in order to be readily observable. It is therefore reasonable to take as a guide that space advertising will need to provide a source at least as bright and extensive as the full Moon.

Solar reflectors have been proposed for such purposes - the Ring of Light, the Space Billboard are examples. The Star of Tolerance was somewhat different but was still proposed to be as bright as Jupiter and designed to create an artificial “double star”. So far, fortunately, no such project has been implemented.

Solar reflectors have limitations. They must be very large (km size) and they are limited by the amount of twilight they can reflect. Because they reflect sunlight, they will be twilight features. Why does this interfere with astronomy? It is likely that putative advertisers will want to raise the orbits of their reflectors to maximise contrast between sky and reflector so as to enhance their message. This will make more of the night unusable - unusable, not just the avoidance of trailing by debris. Several reflectors each as bright as a full Moon will pose a threat to a range of astronomical observations - not just faint objects. Such reflectors will be there every night not just the week either side of full Moon.

The Znamya project will test a 25 m solar reflector on Nov 09, 1998. This has a brightness of 5 - 10 full moons - well in excess of the brightnesses quoted in the previous paragraph. A 60/70 m reflector is expected to be launched in 2000 and a 200 m reflector having a brightness of 10 - 100 full moons will be launched further downstream. The earlier assumption of a brightness of 1 full Moon is soon to be surpassed by one or two orders of magnitude! The pressure to use such reflectors commercially will be very great - indeed astronomy’s nightmare scenario has been brought significantly closer.

The twilight limitations of the solar reflector are already recognised. There has been a proposal to use lasers to produce holographic images. Image brightness will depend on the power of the lasers used and that is, in part, a matter for willingness to spend. Advertising brighter than 10-100 full moons may therefore be a possibility *in dark sky time.* Were advertising from space to be acceptable, there is no doubt that advertising would eventually become an all night, all sky phenomenon. In that eventuality, observational astronomy from the ground (and perhaps from space) would be dead.

If observational astronomy is to survive as an effective tool for studying the Universe, there will have to be an unequivocal moratorium on space advertising. Such an International Agreement is not yet over the horizon despite its urgent need. The IAU is seeking World Heritage Status for the Night Sky. A view of the heavens is part of the heritage of mankind, an inspiration to enquire and a tool of considerable use. That heritage should be actively championed and protected - not just for the astronomers.

6. And Finally

Radio band width is in short supply. We all know the severe problems this causes observational radio astronomy. But now satellite engineers are discussing, and indeed ESA has implemented with SPOT-4, laser communication between satellites and with the ground. The lasers operate in the red - at approximately 8000 Å. The optical and infra-red spectrum are not regulated like the radio spectrum. If such laser communication systems become universal, will optical and infra-red astronomy soon be in the position of radio astronomy - grudgingly confined to narrow spectral regions? The radio astronomers were represented on the International Telecommunications Union from 1958. Perhaps it is time for optical and infrared astronomers to learn the lessons of radio astronomy and act now to ensure that laser beam communication does not affect sustained optical and infrared observations.

It is by recognising the multifaceted threat to astronomical observation that astronomy may be able to survive. It is not just light pollution, or pressure on radio bandwidth, that must be resisted - it is all forms of degradation of the conditions for high grade astronomical observation. At some times some frequencies may be under more threat than other frequencies. But astronomers should be aware that the forms of the threat can change on short timescales. The efforts focussed on combating particular threats should also allow for support for other differently beleaguered colleagues. There is a tremendous task to ensure proper public appreciation of astronomy's problems - a public often wonderfully sympathetic. We spend much effort explaining the power of astronomical objects - but we do not spend time explaining the inverse square law which makes those same powerful objects so difficult to detect.

We face a difficult task - but the consequences of ignoring that task are unthinkable for astronomy. We have to convince patrons and public alike of the threat to astronomy - and above all we have to convince our colleagues that the threat is real and unlikely to go away.

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