MONITORING VARIATIONS TO THE NEAR-EARTH SPACE ENVIRONMENT DURING HIGH SOLAR ACTIVITY USING ORBITING ROCKET BODIES

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1. INTRODUCTION

A space object's general characteristics can be substantially influenced by changes in the magnetosphere, ionosphere, and thermosphere environments. These space weather effects can vary according to the space object's orbit, position relative to certain regions in space, the severity of solar activity, and many other factors. Outcomes can range from minor and easily recoverable to total breakdown. Further, technology has advanced such that satellite components have become smaller and smaller, and these micro-systems are increasingly more susceptible to the highly energetic solar particles associated with intense activity. Therefore, additional study of the significance of space weather events on Earth-orbiting objects would be beneficial.

A rotating rocket body in orbit experiences a magnetic torque due to the Earth's magnetic field that results in an exponential decay of its rotational frequency and a variation on the axis of rotation. The Photometric Periods of Artificial Satellites [1] database consists of over 60,000 period measurements, mostly visually acquired, dating back to 1958. Although this database validates this predicted exponential decay in rotation rate, many anomalies have been observed, including increased rotational frequencies. Theories for the causes of these anomalies range from leaking fuel tanks to interaction with the local space environment.

Our program aims to complement the current visual database through CCD and video photometric observations of rotating rocket bodies using a portable 0.35-meter telescope and the Magdalena Ridge Observatory's 2.4-meter telescope. The goal is to generate a detailed astrometric and photometric database for a small set of targets at different orbital altitudes in order to study the variability in orbital motion and the rotational angular momentum vector, particularly during times of high solar activity. The National Oceanic and Atmospheric Administration (NOAA) provides daily information and forecasts of solar variations, so correlation of ground-based observations with enhanced periods of activity is immanently feasible. By studying these effects for the somewhat simplistic case of a rocket body, we hope to provide the necessary data required to predict the effects on working satellites of a more complex shape.

2. MONITORING THE SPACE ENVIRONMENT

Changes in the magnetosphere, ionosphere, and thermosphere effect the space environment in a quantifiable manner. For example, magnetic storm activity can result in orders of magnitude increases in the density of the upper atmosphere as a result of heating in the lower atmosphere due to the precipitation of energetic charged particles. Fig. 1 illustrates how a geomagnetic storm can change the orbits of resident space objects unexpectedly, depicting the loss of spacecraft positions during the March 1989 super-storm.

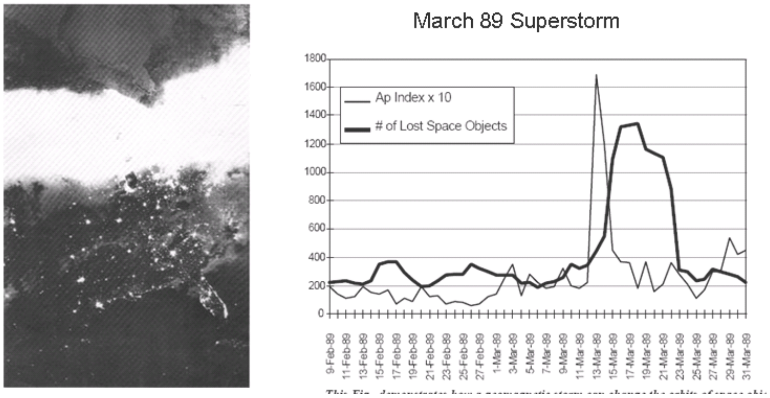

Fig. 1 Effects of the March 1989 magnetic super-storm. Note the temporal correlation between the increase in the Auroral Ap index and the number of space objects lost by NORAD. The loss is because orbit changes are brought about by increased upper atmospheric density.

This research initiative examines the effects on objects in the space environment in response to solar “weather”. The protocol we have established includes monitoring the effects of solar activity (e.g., solar flares or coronal mass ejections) on tumbling rocket bodies as a function of various scale heights above the Earth. When NOAA posts a high activity alert, we will obtain observational data on various target objects and analyze any changes over time, both while the storm activity is in progress, and in quiet times for a baseline comparison. The objective is to acquire a scientific database that records with photometric precision the object’s position, rotation rate, and notes any color changes to the surface. We will have acquired a database of information for these targets in the course of executing this analysis which should be comprehensive within a three year period. Numerical models which aim to improve the predictability of space weather will be able to incorporate these data points as ground truth, and perhaps gain some insights into the physical processes driving any changes detected.

3. INITIAL OBSERVATIONS

In order to initiate this analysis, a test program has been set up using a simple video camera mounted on the 12-inch acquisition scope of the Magdalena Ridge Observatory’s (MRO) new fast-tracking (maximum slew rates are 15°/sec) 2.4-meter telescope facility (see Fig. 2). The target selected for the first observational campaign is the Russian Zenit-2M rocket body (see Fig. 3 for an example of this class of rocket). The rocket recently (June 29, 2007) launched the classified military *Cosmos* satellite and its orbiting remnant is now identified as NORAD 31793.

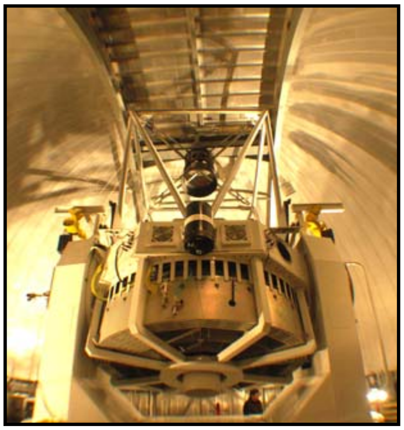

Fig. 2 The Magdalena Ridge Observatory’s fast-tracking 2.4-meter telescope. The 12-inch acquisition telescope (in the center of the picture) was used for the data collected in this analysis.

Fig. 3 The Russian Zenit-2M rocket body class of targets shown prior to a launch occurring in December 2001.

The Zenit-2 rocket body was chosen as an initial target since it has a simple cylindrical shape and its recent launch this year will allow us to monitor space weather effects from its baseline injection into the space environment. It is also rotating rapidly which facilitates the separation of variations due to rotation and changing geometry during a single LEO pass. These types of bodies are also observable at various heights above the Earth, making gauging the effects of the changing atmospheric density associated with storms possible with minimal degrees of freedom.

The first data collection for this target class occurred on July 18, 2007; Fig 4 depicts the trajectory of the object as viewed from the facility site. The rocket body's altitude above the Earth was approximately 850 km for this low elevation pass that reached a maximum elevation of 22°. A simple video camera was mounted to the acquisition telescope of the 2.4m telescope, and data was taken to determine the object's period of rotation. A high frame rate CCD camera system will be introduced after the testing phase of this analysis to better record positional information as well as obtain more robust photometry. At the time of the observations, solar activity was minimal, so the data collected thus far will serve as a good baseline.

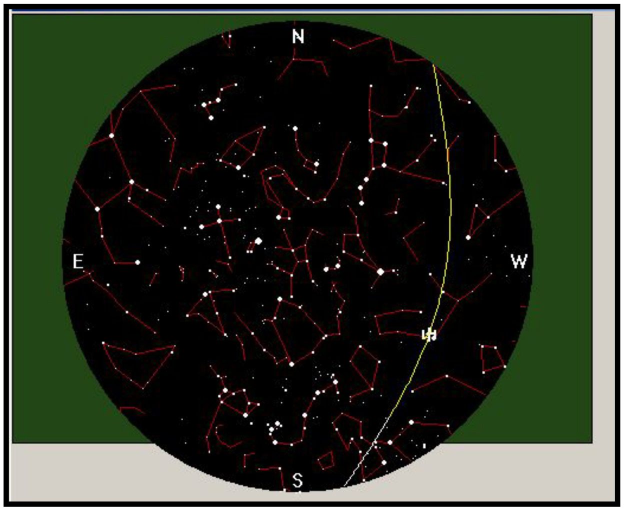

Fig. 4 Trajectory of NORAD 31793 for 18 July 2007 04:22 UT pass.

The ‘flash period’ from the latter part of this pass is 0.57 seconds, consistent with visual observations acquired at nearly the same time [1]. However, Fig. 5 and Fig. 6 show that the lightcurve can be much more complex than implied by a simple flash period that is typically reported by visual observers. In Fig. 5 we show the lightcurve early in the pass when the target was at high solar phase angle. In this case, the lightcurve displays a more complex triple flash pattern with features characteristic of specular reflections. Later in its pass at lower solar phase angle, the object showed the doubly periodic flash pattern expected of a rotating cylindrical object. In both cases, data from several rotations are overplotted with a periodicity of 1.14 seconds, indicating that this is the actual rotation period for the rocket body.

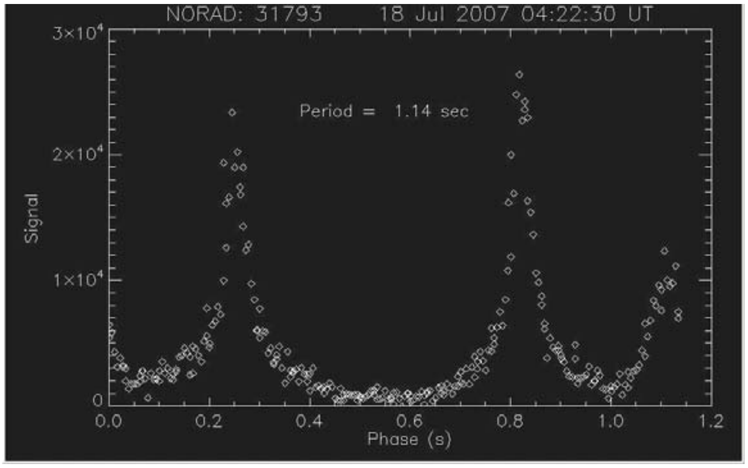

Fig. 5 Lightcurve of the Zenit rocket body (31793) early in pass.

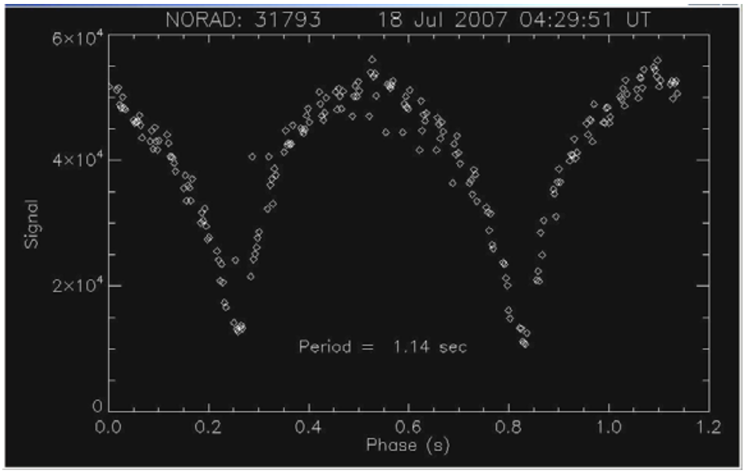

Fig. 6 Lightcurve of the Zenit rocket body (31793) later in pass.

This object will continue to be monitored as a function of solar activity. In addition to the photometric data, positional data will also be acquired. When there are no reference stars in the field, positional data will be acquired from the telemetry of the telescope itself and hence, its precision will be limited to the precision of the mount model, typically a few arc seconds. If reference stars are available, the astrometric precision will be somewhat determined by the exposure times of the camera due to the resultant trailing of the reference stars while tracking the LEO. Despite this, we still anticipate sub-arc-second precision using this method in most cases. The photometric and astrometric data will be analyzed and linked to the physical phenomenon behind changes to its position or rotation rate. The data will be collected as the solar storm is ongoing, so we expect to be able to assess effects as solar activity peaks and drops off again. This should lead to insights that space environment modelers can capitalize upon to improve simulations and forecasting accuracy.

4. FUTURE DIRECTIONS

Initial observations have shown that acquiring data on rocket bodies to assess the space environment is a feasible task for the Magdalena Ridge Observatory to undertake. Improvements to the observational set up will include a better fast framing CCD camera to record photometric and color information as well as acquisition of data through the 2.4-meter telescope itself to achieve higher signal-to-noise for fainter objects. Additional enhancements may include incorporation of polarimetry (on the 12-inch acquisition telescope mounted on the 2.4-meter) to monitor surface changes on these bodies, which would give us the capability to detect changes in the object's general health due to micro-meteorite impacts, for example.

5. REFERENCES

1. McCants, M., PPAS Database. http://www.io.com/~mmccants/bwgs/index.html