What Happened to BLITS? An Analysis of the 2013 Jan 22 Event

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ABSTRACT

The BLITS retroreflector satellite was launched 2009 Sep 17 to conduct scientific experiments in geophysics, geodynamics, and relativity via high-accuracy laser ranging as part of the International Laser Ranging Service. On 2013 Jan 22, an event occurred which prevented further laser ranging. Subsequent investigation revealed a change in both orbit and spin rate that could not be explained without a breakup of BLITS or a collision of BLITS with another object. The identification by the Joint Space Operations Center of a piece of debris associated with BLITS supports these hypotheses. This paper will investigate the available data and assess the likelihood of either hypothesis as an explanation of the event.

1. BACKGROUND

The BLITS (Ball Lens in The Space) nanosatellite is a passive retroreflector spacecraft designed as a proof of concept to demonstrate high-accuracy laser ranging with near-zero target error. Based on the Luneberg lens principle [1], it has full central symmetry (unlike typical corner reflectors) and can provide sub-millimeter laser ranging accuracy.

Built by Open Joint-Stock Company Research-and-Production Corporation "Precision Systems and Instruments" (OJSC RPC "PSI"), BLITS is a composite spherical retroreflector with a diameter of 17 cm and mass of 7.5 kg. As seen in Fig. 1, BLITS consists of two outer hemispheres made of a low-refraction-index glass and an inner ball lens made of a high-refraction-index glass [2]. The hemispheres are glued over the ball lens; the external surface of one hemisphere is covered with an aluminum coating protected by a varnish layer.

BLITS was launched 2009 Sep 17 into a near-circular, 830-km altitude orbit at 98.8º inclination as a piggyback payload with the Meteor-M 1 spacecraft.

The Russian and International Laser Ranging Networks tracked BLITS for 40 months following its launch with an average accuracy of 5–10 mm rms (and as good as 0.5 mm). On 2013 Jan 22, Changchun Station, China tracked BLITS from 01:20:51–01:21:22 UTC and Yarragadee Station, Australia tracked BLITS from 01:40:06–01:45:21 UTC [3]. All subsequent attempts to laser range BLITS were unsuccessful.

Within a day, NORAD two-line element sets (TLEs) produced by the Joint Space Operations Center (JSpOC) began showing a clear change in the orbital period for BLITS (see Fig. 2). By Jan 26, it was clear that the mean semi-major axis had decreased by 127–142 m. Since BLITS had no propulsion or attitude control systems, some event had occurred to cause this change.

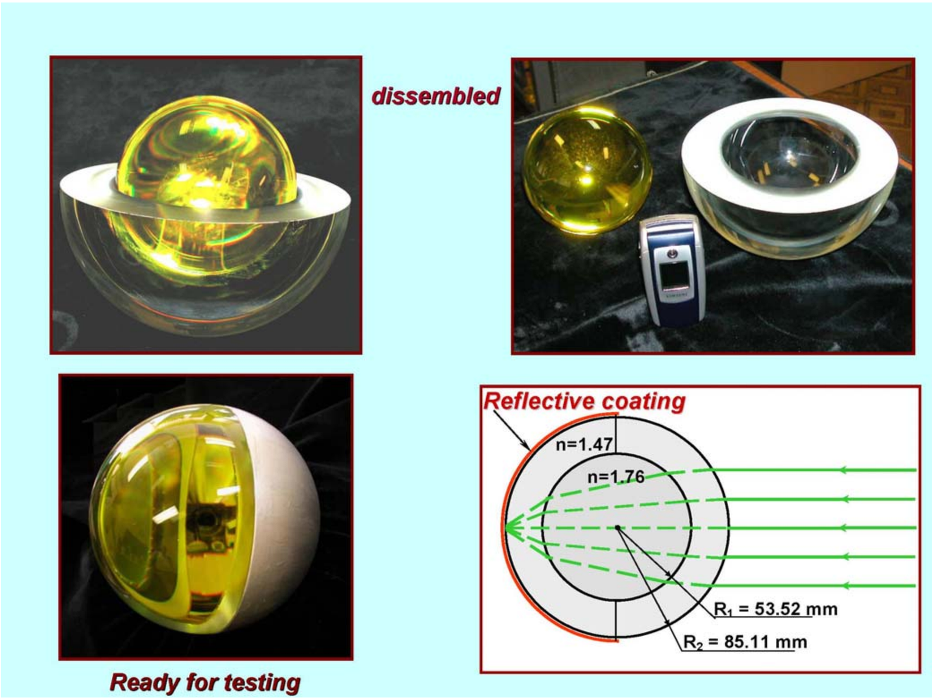

Fig. 1. BLITS Satellite

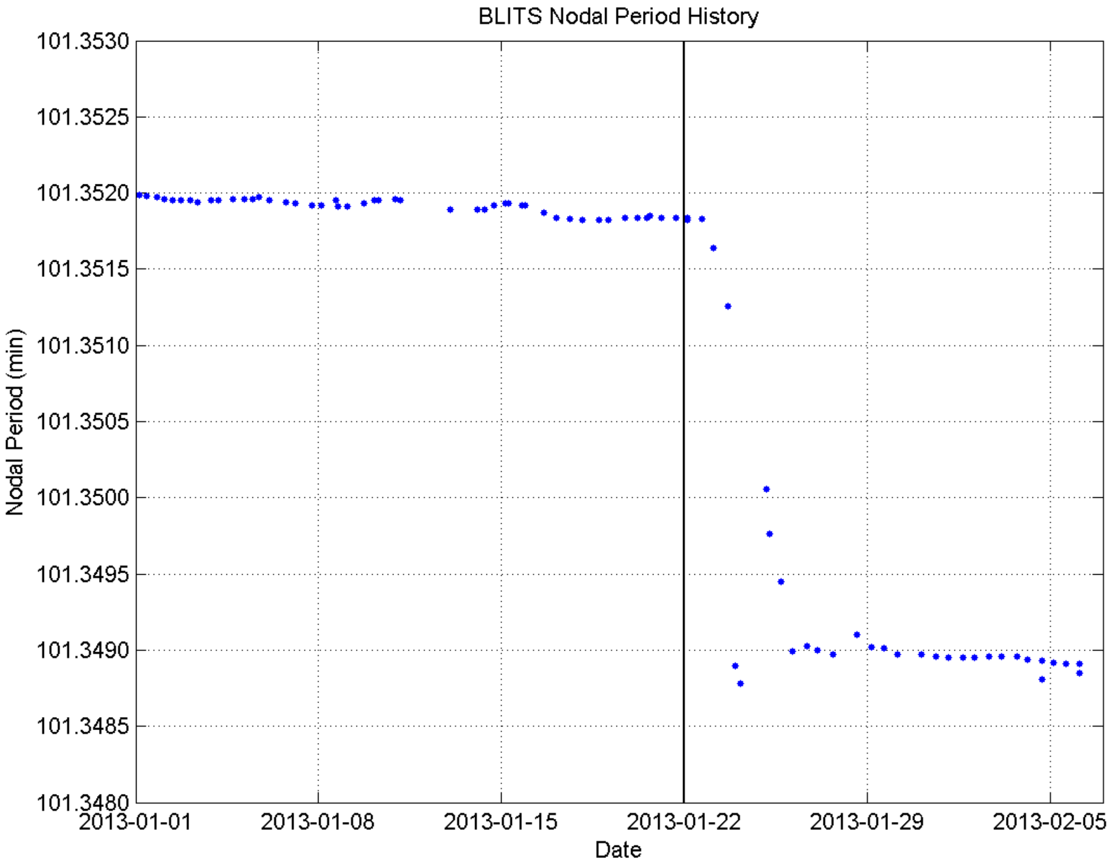

Fig. 2. BLITS Nodal Period History

2. DETERMINING THE TIME OF THE EVENT

The first objective of the analysis was to determine the time of the event. Researchers at OJSC RPC "PSI" used a method to smooth the TLE data for one week both prior to and after the event [4]. They then examined these two smoothed solutions to determine the time of minimum distance, whey they determined to occur between 07:56:41 and 07:59:04 UTC on Jan 22, with a minimum separation of about 200 m.

Since one possible explanation for the change in orbit would be that BLITS was struck by a piece of debris, OJSC RPC "PSI" contacted the Center for Space Standards & Innovation (CSSI) to inquire whether there were any close approaches with BLITS around the time they determined for the event. A search of the SOCRATES report released just prior to the event (2013 Jan 21 at 14:08 UTC) showed only two conjunctions within 5 km on Jan 22 and that one of them occurred at 2013 Jan 22 07:56:51.755 UTC—just 10 seconds into the predicted event time window.

Given the proximity of the conjunction to the prediction and a 1-in-300 chance of randomly occurring within the window, our initial conclusion was that BLITS might have been struck by this piece of FengYun 1C debris (NORAD Catalog Number 30670). There was, however, no corresponding change to the orbit of 30670 seen in its TLEs, which eventually ruled out this hypothesis as the cause for the change in the BLITS orbit.

While working to refine the data used to determine the time of the event, the JSpOC released (on 2013 Mar 3) a TLE for a piece of debris associated with BLITS. The initial assessment by the JSpOC was the debris had been generated by a breakup and not a collision. Given the construction of BLITS, it was hypothesized that the satellite might have come apart due to thermal stresses. This hypothesis would have to be further examined to determine what had really happened.

However, having orbital data for the piece of debris provided more data to determine the time of the event. CSSI propagated the first debris TLE (based on the rev number assigned to this object, it had been tracked as an analyst satellite since Jan 26) back to find the closest approach with the last pre-event TLE (Element Set 623) and then looked for the time when the debris had a zero cross-track distance from BLITS. Previous analysis of collisions (FengYun 1C; Iridium 33 and Cosmos 2251) had shown it was possible to determine the event time not by looking for when the pieces were closest to the pre-event object, but when the pieces had the minimum cross-track dispersion.

Applying this approach for the 39119 TLE and the best post-event TLEs for BLITS (Element Sets 630, 631, 637, 638, and 639) showed a most likely event time of 02:53-02:57 UTC. Neither time corresponded to a conjunction within 5 km of anything in the public TLE catalog. Therefore, the event would have had to been caused by a breakup or a collision with an object too small to be tracked by the US Space Surveillance Network.

The JSpOC subsequently released results from their internal Special Perturbations Differential Correction (SPDC) time residual plots and COMBO (Computation of Miss Between Orbits) runs between the BLITS pre-event SP orbit and the BLITS post-event and BLITS debris SP orbits, which showed closest approach times of 03:06:49.789 and 03:06:25.049 UTC, respectively. The computed miss distances were 68 m and 74 m, respectively. A General Perturbations (i.e., using TLEs) COMBO run for Jan 22 showed no objects with a miss distance less than 20 km had any discernible change in their orbits. Again, these results suggest the event would have had to been caused by a breakup or a collision with an object too small to be tracked by the US Space Surveillance Network.

3. EXAMINING THE BREAKUP HYPOTHESIS

To fully consider what might have happened to BLITS requires an in-depth analysis of the hypothesis that BLITS came apart due to a mechanical failure of the seam where the two outer spheres were joined. Other breakup modes, while possible, seem unlikely without some external input.

Researchers at the Korea Astronomy and Space Science Institute and the Space Research Institute of the Austrian Academy of Sciences have collected extensive observations to determine the BLITS spin rate and spin axis orientation over the period from 2009 Sep 26 to 2012 Jun 18 [5]. They determined a mean spin period of 5.613 s, RMS = 11 ms. This result is supported by observations collected by OJSC RPC "PSI" on 2012 Sep 11 (Fig. 3).

However, in observations collected after the event on 2013 Feb 16, it is clear that the spin period had changed significantly (Fig. 4), with a new estimated spin period of 2.1–2.2 sec. Contrary to expectations based on the principle of conservation of angular momentum, it would appear that the angular momentum actually increased significantly as a result of the event.

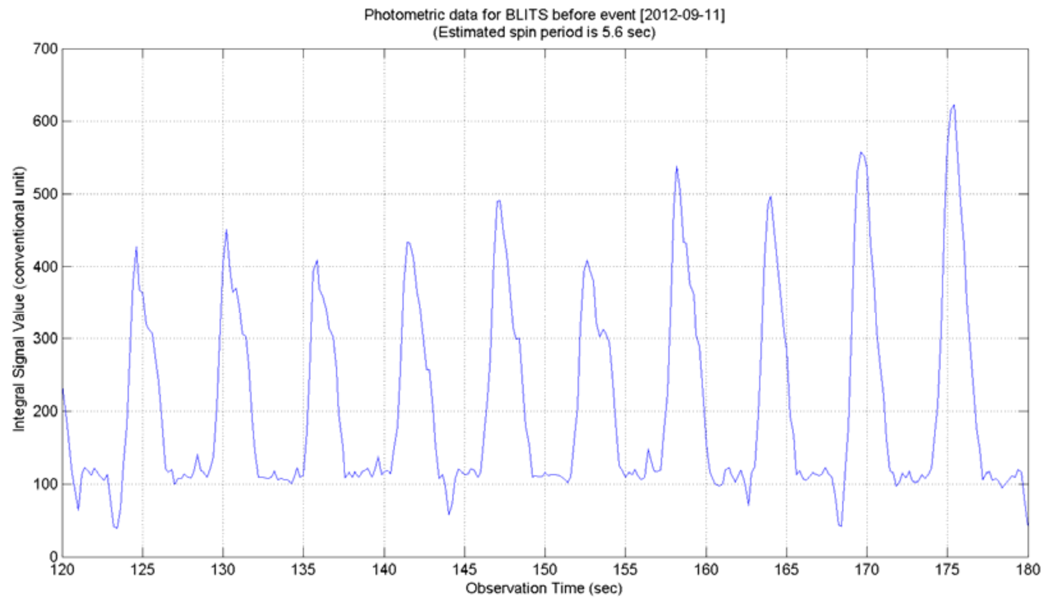

Fig. 3. BLITS Pre-Event Photometric Data from 2012 Sep 11

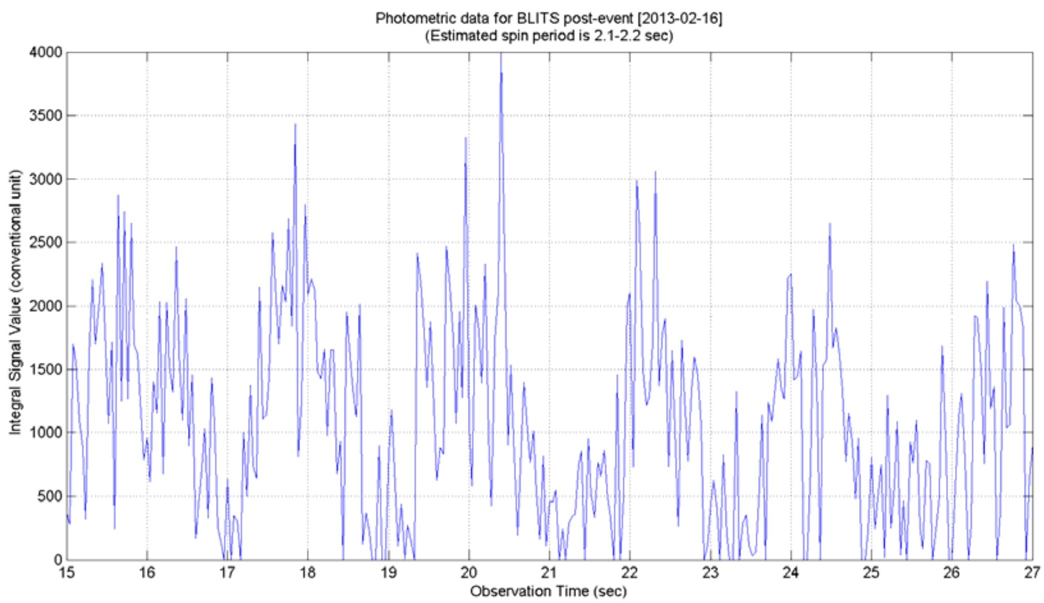

Fig. 4. BLITS Post-Event Photometric Data from 2013 Feb 16

Given the simple design of BLITS, it was possible to perform detailed analysis examining the moments of inertia before and after the event, along with the measured spin rates and spin orientation, to determine the expected spin rate after a simple mechanical failure, as shown in Fig. 5.

Initial work done by Analytical Graphics, Inc. (AGI) showed that if the angular momentum vector was aligned with the orbit momentum vector, the spin rates of the individual pieces after the breakup should be identical to the intact

BLITS satellite prior to the breakup. That work also showed it was possible to impart a change in velocity for each piece relative to the pre-event BLITS orbit, as shown in Fig. 6.

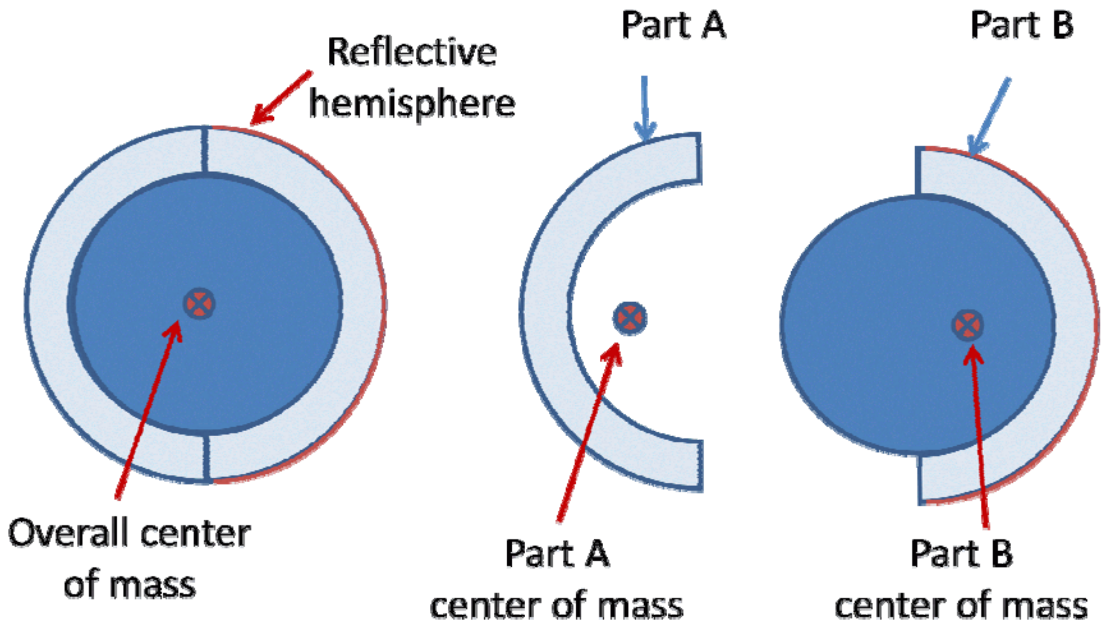

Fig. 5. BLITS Mechanical Failure Hypothesis

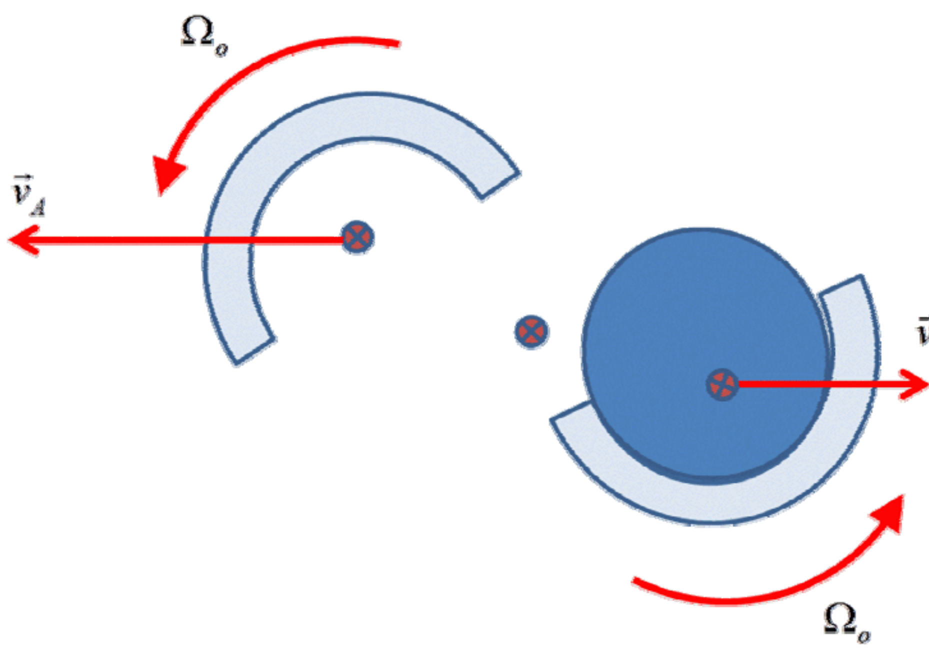

Fig. 6. BLITS Post-Breakup Spin and Velocities

Factoring in the measured pre-event spin rates and spin orientation, along with the moments of inertia of the pieces before and after the breakup, AGI showed that the spin rate would increase slightly from 61.4 deg/s to 71.7 deg/s (spin period change from 5.6 s to 5.0 s). Clearly, this type of breakup could not explain the observed change in spin rate.

AGI also showed that the breakup would impart a change in velocity of 2.84 cm/s for the smaller piece and 1.71 cm/s for the larger piece. Calculating the state for BLITS (Element Set 623) at the JSpOC event time of 03:06:50 UTC and knowing the specific energy to be:

$$E = \frac{v^2}{2} - \frac{\mu}{r} = -\frac{\mu}{2a}$$

a decrease in the semi-major axis of 127–142 m would require a change in velocity of 6.6–7.4 cm/s (independent of the mass of the object)—apparently too large to be caused by the breakup hypothesis. Note that a breakup producing a smaller debris object would mean the parent object was more massive than considered in this analysis and would have an even lower change in velocity, effectively ruling out all possible spontaneous breakup events.

The final piece of evidence weighing against a simple mechanical failure can be found in the radar cross-section (RCS) data provided by the JSpOC. As can be seen in Fig. 7, the measured RCS values for BLITS have been very stable, with a value of 0.082 m^2, since the beginning of 2012. There is very little, if any, change in the RCS value after the event. When combined with the RCS value of 0.0018 for the BLITS debris—a factor of almost 7 smaller in size or about 2.5 cm—it would be far too small to represent even the smallest piece of a simple mechanical breakup (the inner sphere at 10.7 cm).

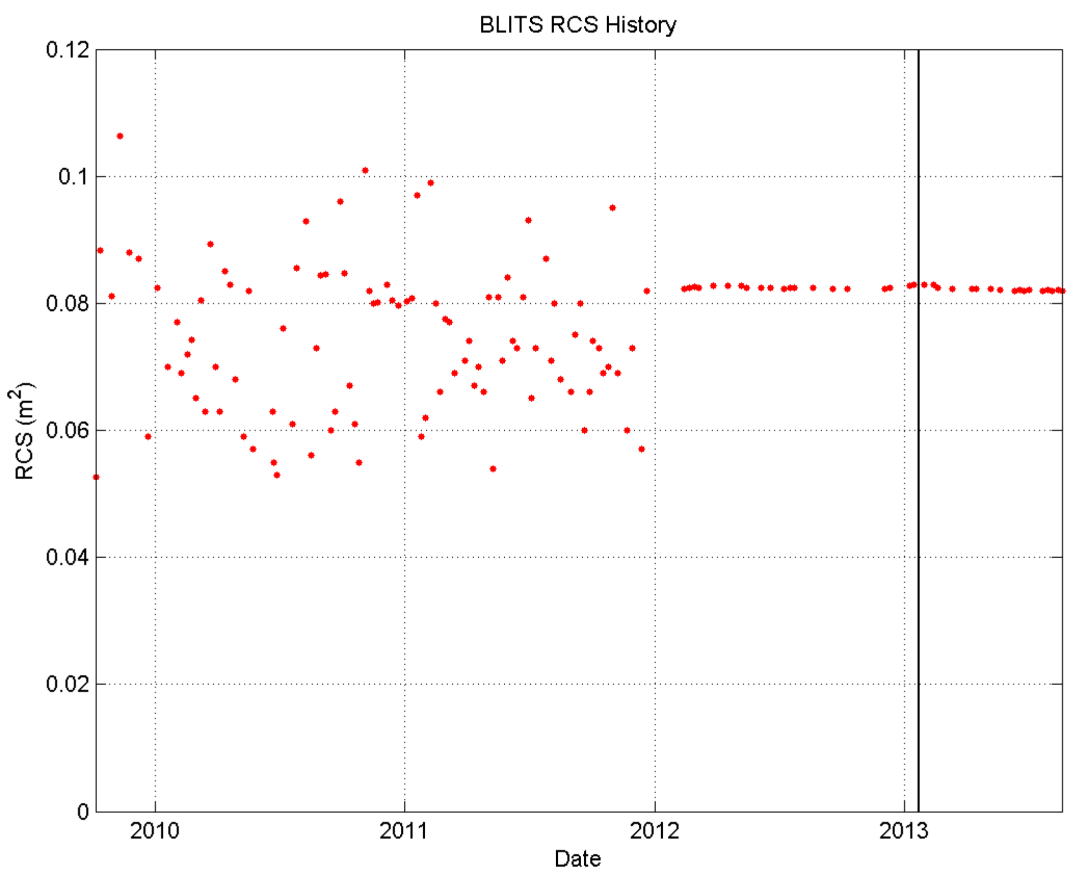

Fig. 7. BLITS RCS History

4. ANALYSIS OF COLLISION WITH SMALL DEBRIS

The final hypothesis to examine is whether BLITS could have been struck by an object large enough to cause the observed decrease in the semi-major axis but too small to be tracked by the SSN. A lower limit on the mass of this notional untracked object can be determined by assuming an elastic collision and applying the laws of conservation of energy and conservation of momentum.

If we perform these calculations in the BLITS pre-event frame, the equations are:

$$mv = M(\Delta v) + m(v') \text{ [Conservation of momentum]}$$

$$mv^2 = M(\Delta v)^2 + m(v')^2 \text{ [Conservation of kinetic energy]}$$

where M is the BLITS mass (7.53 kg), m is the mass of the untracked object, v and v' are the pre- and post-collision relative velocities of the untracked object, and Δv is the change in BLITS velocity, which yields:

$$\Delta v = \frac{2m}{M+m} v \text{ or } m = \frac{M \Delta v}{2v - \Delta v}$$

Assuming a head-on collision with an untracked object traveling in the opposite direction in the BLITS orbit, then the relative velocity is 14.894 km/s and the mass of the debris required to produce the observed change in semi-major axis would be 0.017–0.019 g. Assuming a density the same as BLITS, this would equate to a sphere 2.2–2.3 mm in diameter—far too small to be tracked by the SSN.

In fact, if we look at encounter angles (the angle θ in Fig. 8) less than 180º and assume the untracked object has the same orbital speed as BLITS, it is possible to repeat these calculations to determine the corresponding object size required to produce the observed change in semi-major axis as a function of the encounter angle. As the encounter angle increases, the relative velocity decreases, and a larger overall change in velocity is required to produce the observed in-track change in velocity. The results are shown in Fig. 9.

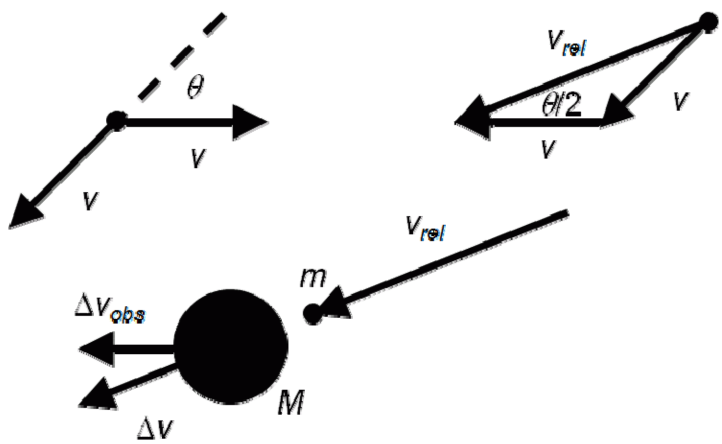

Fig. 8. Encounter Geometry

Even at an encounter angle of 175º (coming from behind), where the relative velocity is 650 m/s, a spherical object with the same density as BLITS and a diameter of 1.86 cm can produce a decrease in the semi-major axis of 142 m. Fig. 9 clearly shows that it would be possible to produce the observed results for virtually any encounter geometry and still be too small to be tracked by the SSN.

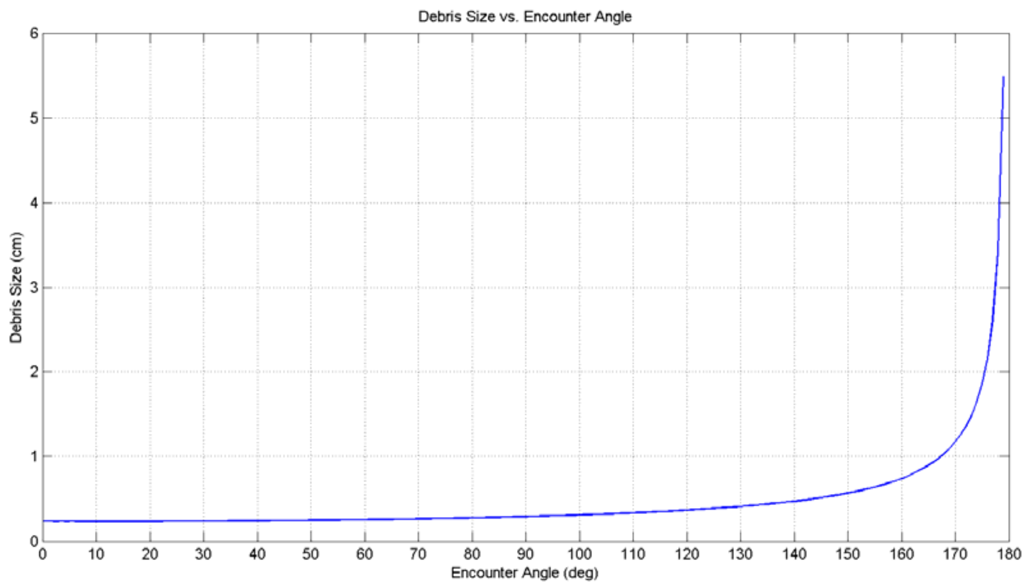

Fig. 9. Debris Size vs. Encounter Angle

In reality, a hypervelocity collision will not be elastic and some energy will have been used to break off the piece of observed BLITS debris. In addition, the collision would have to occur somewhat off axis to produce the observed change in spin rate. So these sizes should be considered as a lower bound. How much energy would be expended or how far off axis the collision would have to be is the subject for further analysis.

5. CONCLUSIONS

It is clear that some event occurred to cause the observed changes in semi-major axis and spin rate for BLITS—a satellite with no propulsion system or moving parts. Our analysis has shown that the event occurred somewhere around 03:06:50 UTC on 2013 Jan 22 and a comprehensive search of all tracked objects showed no objects which came within 20 km of BLITS on Jan 22 had any observed change in their orbit, which would be an indication of a possible collision.

Examination of a simple mechanical failure hypothesis where BLITS might have come apart along its glued seam showed that such an event would not produce a sufficient change in velocity for the larger of two pieces to account for the observed decrease in semi-major axis nor would it result in a significant increase in the spin rate to match the observed photometric observations. When considered together with the relative size of the only debris object cataloged from the event based on the RCS measurements, it is also clear that a breakup that produced these two pieces would produce an even smaller change in velocity and spin rate of the main object—effectively ruling out all possible breakup modes.

Finally, a thorough examination of the mass required to produce the observed change in semi-major axis for an object in an orbit similar to BLITS showed that most encounter geometries could produce the effects with an object far too small to be tracked by the SSN.

As a result, it is the authors' belief that the most likely cause of this event was a collision with an object too small to be tracked by the SSN. This analysis demonstrates the difficulty in determining what actually occurred, due to the complexity of the problem and limitations of the data, but highlights the advantages of collaboration and data sharing in coming to a sound conclusion based on the evidence.

6. REFERENCES

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