Pre-fall Orbit of the Buzzard Coulee Meteoroid

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Summary

A large, bright fireball was widely observed by tens of thousands of eyewitnesses on the evening of November 20, 2008. Subsequently thousands of meteorites fell to the ground and more than 2,500 have been recovered from an area in and near to Buzzard Coulee, Saskatchewan. Many un-calibrated cameras recorded the violent fall of this ~2m boulder. A novel method of calibrating the shadows cast by the fireball has been developed and used to triangulate the atmospheric trajectory. Results show that the rock travelled along a path of 167.5° azimuth at a fairly steep angle of 66.7° altitude. Using timing information with direct measurements of the fireball's position in the sky an initial velocity of (18.0 ± 0.4) km/s has been determined. An atmospheric trajectory and initial velocity are sufficient data to derive the pre-fall orbit of Buzzard Coulee. The resulting orbit shows that the meteoroid was in a near-Earth Apollo-type orbit before impact. Buzzard Coulee is one of only 14 meteorites worldwide to be associated with a pre-fall orbit.

Introduction

A bright bolide was observed by tens of thousands of people in Saskatchewan, Alberta, Manitoba and Montana on the night of November 20, 2008. Eyewitness reports and crude camera calibrations led to meteorites being found one week after their fall on a small pond in Buzzard Coulee, Saskatchewan. Search efforts over the following months have led to over 2,500 fragments being recovered, making the Buzzard Coulee (H4) meteorite the largest fall and probably the most widely observed in Canadian history.

The collision of this ~2m boulder with the atmosphere was recorded by many instruments, including: all-sky cameras, video cameras, security systems, a radiometer and six infrasound stations (Hildebrand *et al.,* 2009). This wealth of data preserves information about the meteoroid including its heliocentric orbit, giving context to the recovered fragments. Many proximal security cameras captured clear images of the shadows cast by the fireball. For the first time, shadows have been calibrated to triangulate a best fit trajectory for the rock travelling through Earth's atmosphere. An accurate trajectory coupled with time and an initial velocity provides sufficient information to derive a pre-fall orbit for this meteorite.

Methodology

A number of nearby security cameras that captured shadows cast by the fireball offer optimal geometry for calibration. Detailed surveys were conducted and calibration images taken at three sites, two in Lloydminster and one in Lashburn, Saskatchewan. Shadow positions were measured in each frame and, using the location of the object casting the shadow, the position of the fireball in the sky was calculated (Figure 1). A series of positions from one location defines a plane of observation in the sky (Figure 2); the intersection of the three planes of observation gives a best fit line for the trajectory through the atmosphere.

An initial velocity is obtained through accurate positional and timing information of the fireball. A police dashboard camera in Devon, Alberta caught clear images of the start of the fireball from ~200 km away. The video operated at standard NTSC video rate so that timing between frames is known. The calibration of this video had an added complication that the police car was moving while recording the fireball, so a series of stellar calibration shots were taken at positions along the street. The stellar images were overlain onto the individual frames so the position of the fireball could be measured with respect to the known positions of the stars.

Figure 1: *Left:* Security camera frame from Lashburn, SK, showing the shadows cast by the fireball; in this case notable shadows are being cast by the light fixtures above the gas pumps. *Right:* Calibration image taken through the security camera, a regular grid pattern was used to measure the shadow positions relative to the object casting the shadow.

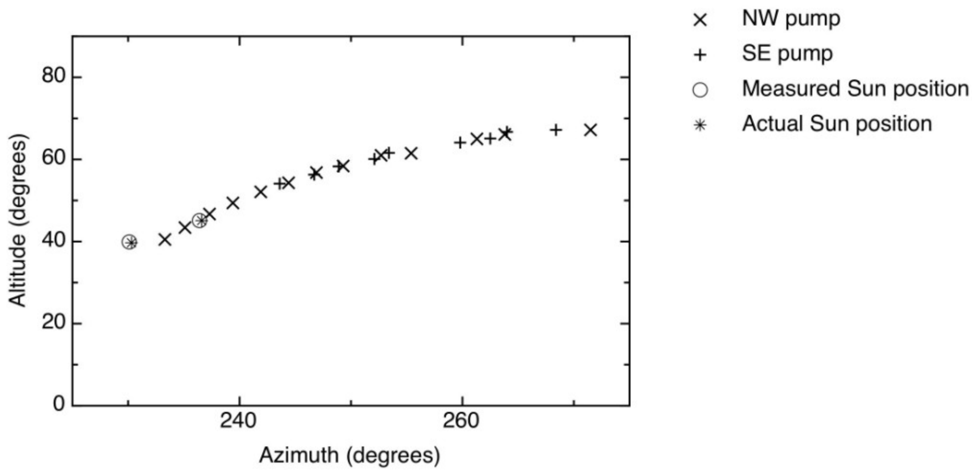

Figure 2: Fireball positions in the sky measured from Lashburn, SK. Different sets of shadows recorded by two cameras at the same gas station were independently calibrated and subsequently found to give excellent agreement. Two test points were used to check the calibration of one camera, these were Sun shadows measured at a given time and compared to the Sun's known position in the sky.

Results and Conclusions

The Buzzard Coulee fireball became luminous at approximately 86 km height to the southeast of Lloydminster. It travelled along a fairly steep trajectory of 66.7° from the horizontal at a direction of 167.5° azimuth. Deviations from the best fit of each of the positions used to determine Buzzard Coulee's trajectory are plotted in Figure 3. The small magnitudes demonstrate the quality of the fit and the even spread of positive and negative values supports the quality of each calibration. Detectable shadows were cast between 63.9 km and 17.6 km above the ground. Many successive fragmentations occurred along the trajectory, and a shower of red fragments was described by many eyewitnesses after the fireball fragmentation was finished. Three large fragments are seen to continue glowing below 12.6 km in a calibrated video record from Biggar, Saskatchewan. These three large fragments are seen in a number of the video records and are believed to have already been recovered (13 kg Johnson fragment, 13 kg Kriz fragment and the 10 kg Mitchell fragment).

An initial velocity of (18.0 ± 0.4) km/s was derived through measurements of the police dashboard camera and confirmed with measurements from a calibrated all-sky camera located in Saskatoon. A pre-fall orbit for Buzzard Coulee has been derived based on this work (Table 1). Prior to collision, the meteoroid was in a fairly evolved Apollo-type orbit with an aphelion extending to Mars. Deriving a pre-fall orbit for a meteorite is a relatively inexpensive way to explore of the distribution of small Solar System bodies, helping to build an understanding of the compositional distribution of the Asteroid Belt and by inference, processes operating during the earliest times of the Solar System. Buzzard Coulee is one of only 14 meteorites worldwide to have fallen from a known orbit, and only the second to come from an evolved near-Earth orbit (Spurný *et al.*, 2009).

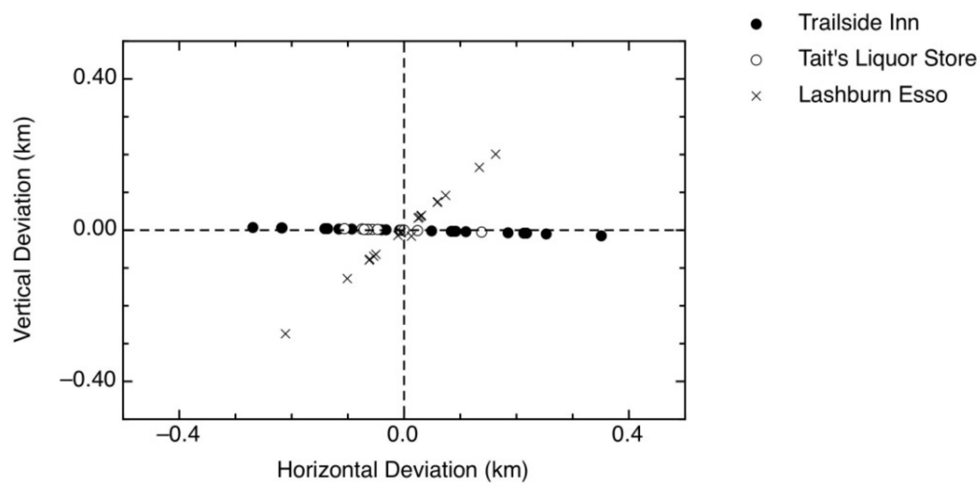

Figure 3: Deviations from the final best fit trajectory in the horizontal and vertical directions for each point measured. All measured positions show relatively small deviations, a few hundred meters at most. The positive and negative values are relatively evenly distributed along the trajectory indicating calibrations lacking systematic errors. The Trailside Inn and Tait's Liquor Store are both located in Lloydminster while the Esso station is in Lashburn, SK. The slope of the deviations for each location is related its geometry of observation with respect to the fireball.

Semi-major Axis	Eccentricity	Perihelion	Aphelion
1.225 AU	0.215	0.961 AU	1.488 AU
Inclination	Argument of Perihelion	Longitude of Ascending Node	True Anomaly
25.486°	212.019°	238.937°	90.957°

Table 1: Derived orbital elements of the Buzzard Coulee meteoroid. It was on a moderately inclined Inner Solar System orbit before impacting the Earth. A semi-major axis larger than one and a perihelion distance smaller than 1.017 AU satisfies the criteria for an Apollo-type near-Earth orbit designation.

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